"UNSTABLE SLOPES: POOR URBAN PLANNING AND RISK MITIGATION"

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ABSTRACT

The research analyzes the relationship between the lack of urban planning and slope instability in the bardas of Neuquén, with the aim of identifying risk zones and assessing the social perception of danger. A mixed-method approach was applied, combining geospatial analysis in QGIS with surveys of local residents. The hazard and vulnerability maps revealed that the neighborhoods of Villa Ceferino, Melipal, and Islas Malvinas show a critical overlap between high geomorphological susceptibility and high social exposure. Despite this, 82% of respondents do not perceive their homes to be at risk, and 64% are unaware of the concept of mitigation, evidencing a significant gap between physical risk and social perception. The results highlight the need to incorporate geological and geomorphological criteria into urban planning and to implement education and monitoring campaigns that strengthen community-based risk management. It is concluded that the integration of technical tools and citizen participation is essential to move toward safer, more resilient, and sustainable urban development.

Keywords: geomorphological risk; urban planning; social perception.

1. INTRODUCTION

Mass removal processes, which include landslides, debris flows, rock falls, and subsidence, constitute geodynamic phenomena with a great destructive capacity for human settlements. Scientific literature has shown that these processes result from complex interactions between natural factors, such as lithology, slope, and precipitation, and anthropic factors associated with disorganized urbanization, deforestation, and intensive land exploitation (Cruden & Varnes, 1996; Dai & Lee, 2002). Their impact in urban areas is particularly critical: they not only cause human and material losses but also compromise the safety and sustainable development of entire communities, especially in contexts of high socioeconomic vulnerability.

The classic review by Cascini, Bonnard, Corominas, Jibson, and Montero-Olarte (2005) highlights that, despite international efforts to reduce the occurrence of disasters—such as the proclamation of the International Decade for Natural Disaster Reduction (1990-2000) by the United Nations—the frequency and intensity of events associated with landslides increased towards the end of the 20th century. This increase is mainly explained by demographic pressure, unplanned urban growth, and the occupation of unstable slopes, factors that, instead of reducing exposure, amplify it alarmingly. In Latin American cities like La Paz, Cusco, or Manizales, the development of marginal neighborhoods on unstable terrain is a paradigmatic example of how the lack of urban planning potentiates the risk of catastrophes (Cascini et al., 2005).

In fact, the interaction between natural processes and human activities has been repeatedly emphasized in the literature. Annan (2002) had already warned that contemporary disasters are not only the result of inevitable natural threats but are, to a large extent, generated or exacerbated by human action. This perspective reinforces the idea that risk management must transcend purely engineering-based approaches and consider social, political, and territorial dimensions. Consequently, hazard and risk zoning, conceived as a central urban planning tool, appears as an urgent requirement to reduce exposure and guide development towards safer territories (Ho et al., 2000; Fell et al., 2005).

However, the scenario of geotechnical risks has transformed in recent decades with the accelerated expansion of urbanization, especially in developing countries. Chen, Lin, Zhang, and Lu (2012), in their study of the Pearl River Delta region in China, show how the combination of excessive urbanization and unfavorable geological conditions has led to significant ground subsidence. This phenomenon, closely linked to the siting of cities on unconsolidated alluvial sediments and the overexploitation of groundwater, generates surface displacements that reach rates of up to $\pm15~mm/year$. The authors stress that these deformations, although gradual, can severely compromise the stability of critical infrastructure and increase exposure to delayed collapses. The case of the Pearl River Delta, one of the most densely urbanized and economically dynamic regions in China, constitutes an illustrative example of how urban expansion without adequate geotechnical criteria produces structural vulnerabilities of great magnitude.

These types of findings are not limited to China. Analogous situations are reproduced in Latin America, where the accelerated growth of intermediate cities and regional capitals has led to the occupation of fluvial terraces, alluvial fans, and unstable slopes, often without soil suitability studies. In such contexts, the precariousness of settlements and the lack of urban regulation make the population the most fragile component of the risk system. Thus, the need to articulate territorial diagnostic tools that allow anticipating disaster scenarios before they materialize is reinforced.

In parallel with the recognition of these problems, the scientific community has developed increasingly sophisticated methodologies for susceptibility and landslide risk analysis. Agboola, Hashemi Beni, Elbayoumi, and Thompson (2024) highlight the role of Landslide Susceptibility Mapping (LSM) models, which, through the analysis of historical inventories and correlation with conditioning factors—such as slope, lithology, land cover, and proximity to drainage networks—allow for the identification of critical zones and the creation of susceptibility maps. These authors, by comparing various machine learning algorithms like Random Forest, Support Vector Machines, and Extreme Gradient Boosting, show that techniques based on artificial intelligence outperform traditional statistical methods in terms of precision and generalization capacity. Their research, conducted in North Carolina (USA), achieved AUC values above 99% in test scenarios, confirming the effectiveness of hybrid modeling approaches for prospective risk management.

Nonetheless, despite such advances, relevant gaps still exist. As Agboola et al. (2024) acknowledge, the generation of quality databases remains a crucial challenge. The absence of complete inventories, the difficulty of obtaining homogeneous data on precipitation, or the lack of standardized criteria for selecting zones unaffected by landslides introduce uncertainties into the modeling. Added to this is the fact that, in many cities in developing countries, resources for acquiring high-resolution geospatial data and implementing continuous monitoring systems are scarce, limiting the practical application of state-of-the-art methodologies.

In summary, the field of study on mass removal in urban areas is characterized by three complementary dimensions. First, the recognition of the magnitude and complexity of the problem on a global scale, where the combination of natural threats and anthropic pressures has increased the risk in vulnerable cities (Cascini et al., 2005). Second, the identification of new manifestations of instability associated with accelerated urbanization processes, such as induced subsidence in the Pearl River Delta (Chen et al., 2012). And third, the development of innovative methodologies based on geotechnologies and machine learning, which offer more precise tools for risk prediction and management (Agboola et al., 2024). However, the effective articulation of these three dimensions—problem diagnosis, identification of new urban risk phenomena, and application of advanced modeling techniques—has not yet been sufficiently realized in research centered on vulnerable and poorly planned settlements. This absence of comprehensive studies constitutes a research niche that is urgent to address. Territorial planning in contexts of informality and urban precariousness cannot be based solely on extrapolations from successful cases in countries with high data availability; it requires methodologies adapted to realities of information scarcity, institutional limitations, and high social exposure.

Facing this gap, this article proposes to develop an exercise in mapping and zoning risks from mass removal processes in vulnerable and poorly planned urbanizations, integrating conceptual approaches to risk management (Cascini et al., 2005), empirical evidence on the effects of accelerated urbanization (Chen et al., 2012), and advanced modeling methodologies in susceptibility (Agboola et al., 2024). The research is conceived as a contribution in two senses. On one hand, it seeks to generate applied knowledge that allows for the identification of high-risk zones and guides mitigation and prevention actions in critical areas. On the other hand, it aims to contribute to the academic debate on how to adapt and transfer methodologies of high technical complexity to contexts where resources, data, and institutional capacity are limited, but where social needs and the urgency to reduce vulnerability are greater.

Likewise, this initiative seeks to reclaim and make visible the contribution and impact of professionals linked to the geological sciences, whose knowledge of processes and variables that continuously modify the environment in which humans live can have a more than significant impact on the community. In short, the current research is situated at the intersection of applied science and territorial justice: a space where knowledge about geodynamic processes and advanced modeling tools are put at the service of communities exposed to increasing risks, in order to build safer, more resilient, and sustainable cities.

2. METHODOLOGY

Research Approach The research adopted a mixed-methods approach, combining quantitative and qualitative methods. The quantitative component focused on the development of geomorphological hazard maps for the "bardas" (cliffs/bluffs) of Neuquén, while the qualitative component addressed the level of awareness and risk perception by the population that inhabits or frequents the area.

Data Collection Data collection used primary and secondary sources. Primary sources included the development and application of surveys aimed at evaluating the community's degree of knowledge, perception, and preparation for geomorphological hazards, such as landslides, rock falls, and slope erosion. The questionnaires were designed and distributed virtually, through digital forms sent to the population.

Secondary sources included topographic, geological, and geomorphological information from digital elevation models (DEMs), geological maps, and public databases. From these inputs, thematic maps of slope, lithology, landforms, and land use were created, which were used to generate the hazard maps. The processing and analysis of spatial information were carried out in QGIS, taking the methodological work of Agboola et al. (2024) on landslide susceptibility mapping using geospatial techniques as a reference.

Additionally, background information was collected from media outlets where events or situations related to the geomorphology of the "barda" that affected the nearby population were recorded. This news allowed for the identification of specific cases of social impact, such as road blockages, rock falls, or damage to homes, and served to contextualize the perception of risk within the general analysis.

Participants Residents and frequent users of the Neuquén slopes participated in the research, including residents of nearby neighborhoods. In total, [50] surveys were collected. The sample was selected considering different age ranges, educational levels, and degree of knowledge of the area, with the objective of obtaining a representative view of the local population.

Data Analysis Spatial data were analyzed using weighted overlay and interpolation methods, assigning a relative weight to each variable (slope, lithology, morphology, and land use) according to its influence on slope stability. In this way, geomorphological hazard maps were created that classify the zones into different susceptibility levels.

Furthermore, the survey results were examined through descriptive statistics in order to interpret the levels of awareness, risk perception, and preventive measures adopted by the population.

Finally, the qualitative data from news and testimonies were analyzed to establish relationships between the geomorphological dynamics of the area and the observed social impacts, integrating the results into a joint interpretation of the geomorphological risk on the Neuquén slopes.

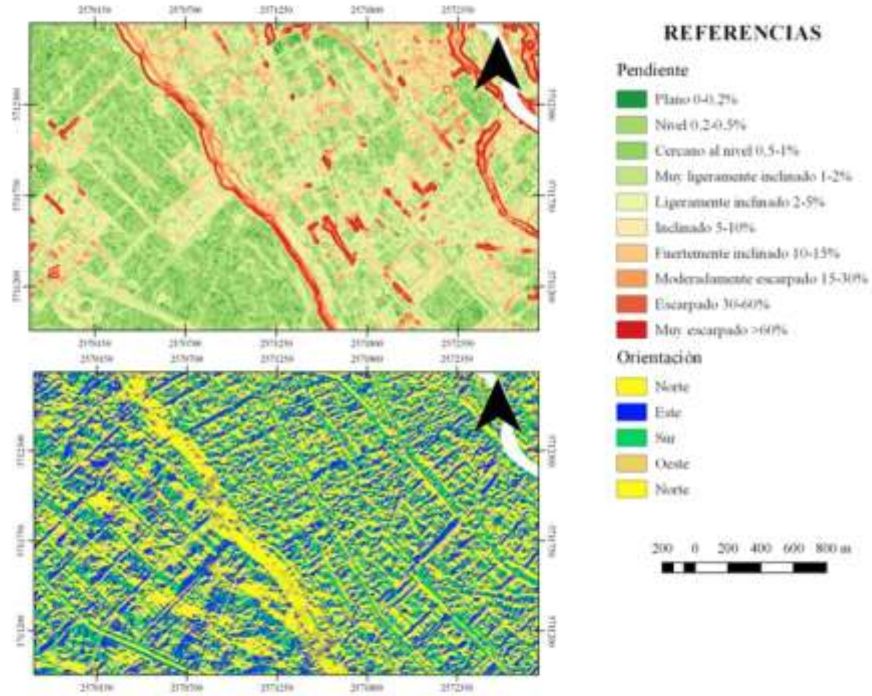
3. RESULTS

3.1 Geomorphological characterization of the study area

The analyzed area corresponds to the "bardas" (cliffs/bluffs) sector located north of the city of Neuquén, including the neighborhoods Melipal, Balcón de la Ciudad, Bardas Soleadas, Villa Ceferino, Terrazas Neuquén, and Islas Malvinas. The geomorphological interpretation allowed for the identification of a steep relief, dominated by sharp slopes and accumulation zones at their base. In the upper part, gently undulating structural surfaces are observed, while the fronts of the "bardas" are dominated by abrupt talus slopes where water and gravitational erosion have shaped gullies and localized detachments. The materials mainly correspond to sandy and silty sediments of fluvio-lacustrine origin, with interbedded tuff levels, which conditions the instability of the slopes against erosive processes or water saturation.

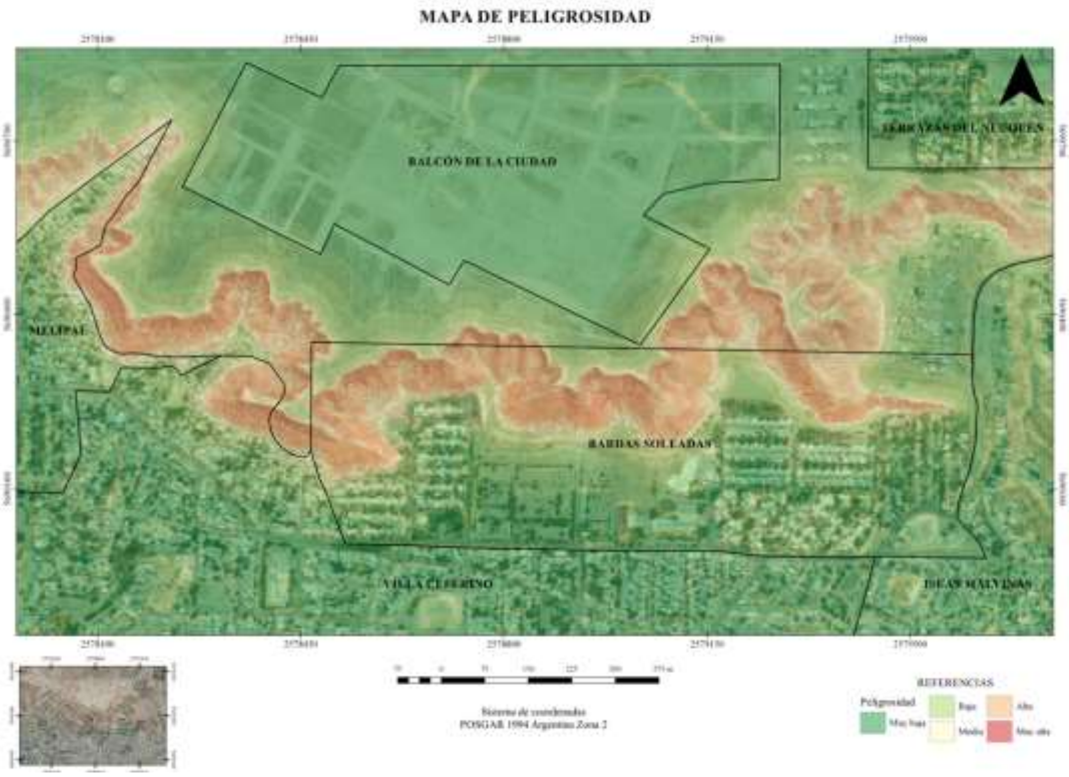
3.2 Analysis of slopes and orientation

The slope map shows values ranging from flat surfaces (<2%) in the piedmont and urbanized areas, to very steep sectors (>26%) on the fronts of the "bardas". These areas of steeper slope coincide with the main scarps and active erosion zones, constituting the sectors with the highest susceptibility to mass movements. As for the orientation of the slopes, south and southeast exposures predominate, which implies a greater incidence of solar radiation and lower moisture retention, factors that can accelerate weathering processes and favor the disintegration of surface materials.



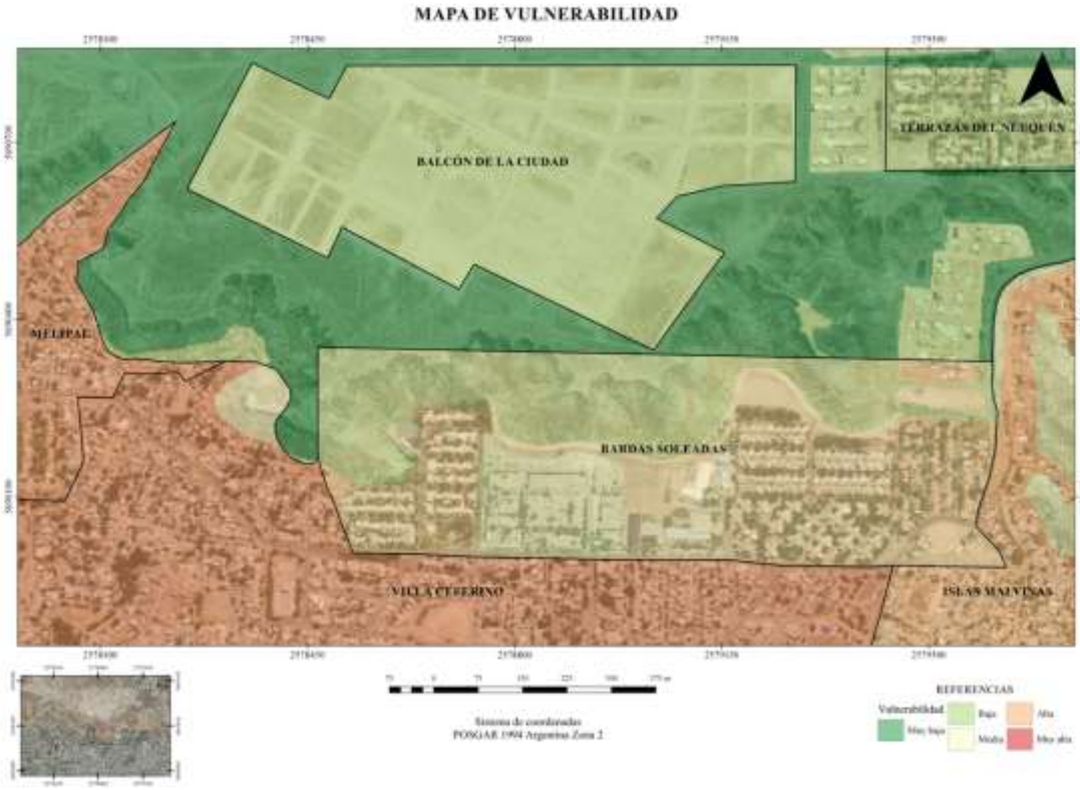
3.3 Hazard maps

Based on the geomorphological analysis, slopes, and lithological characteristics, hazard maps were developed for different water contribution scenarios (2.63 and 6.75 mm/day). In both cases, a high concentration of medium to very high hazard zones is observed on the fronts of the "bardas" bordering the Balcón de la Ciudad and Bardas Soleadas neighborhoods. The Melipal and Villa Ceferino sectors also present critical areas due to the proximity of housing to the slopes and the existence of concentrated runoff. The areas classified as low to very low hazard correspond to the urbanized zones of the piedmont, where the slope is reduced and active geomorphological processes are minimal.



3.4 Vulnerability map

The vulnerability map integrates physical information with the degree of exposure of the population and infrastructure. The areas of greatest vulnerability are located in Villa Ceferino, Melipal, and Islas Malvinas, where there is a higher density of housing near the base of the "bardas", much of which has precarious construction conditions or poor drainage infrastructure. Conversely, the sectors corresponding to Balcón de la Ciudad and Terrazas del Neuquén show low vulnerability, due to their higher elevation, recent urbanization, and better infrastructure conditions.



3.5 Integration of results

The superposition of the hazard and vulnerability maps allowed for the identification of critical zones where high levels of geomorphological hazard and high social vulnerability coincide, mainly in the southern sector of Bardas Soleadas and Villa Ceferino. These results indicate the need to consider local geomorphology and urban occupation as key factors in risk assessment, as well as the importance of promoting awareness and territorial planning to minimize future impacts.

3.6 Results of the social component: surveys on perception, knowledge, and exposure

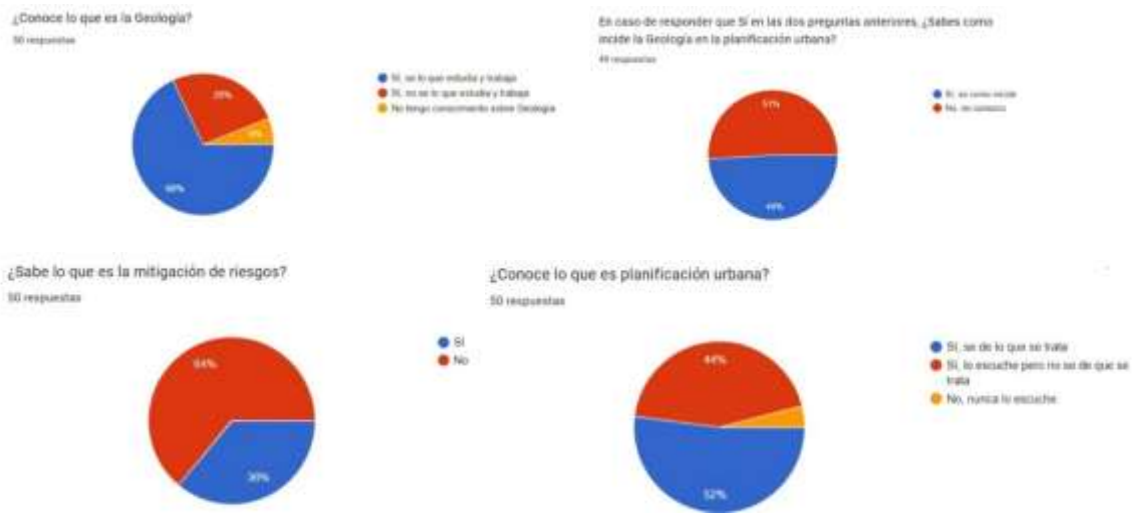
3.6.1 Description of the sample

50 individuals residing in or frequently using the "bardas" in the northern area of Neuquén city were surveyed. The age distribution shows a clear preponderance of young-adult population: 50% of respondents belong to the 18-25 age group (n= 25), 40% to the 25-55 age group (n=20), 6% to those over 55 (n=3), and 4% to the 10-18 age group (n=2). Variations in the number of responses per question are due to specific skips/omissions in the form: for most questions n=50, while some specific questions yielded n=49, 32, or 30 as indicated in each section.

3.6.2 Knowledge about geology and mitigation

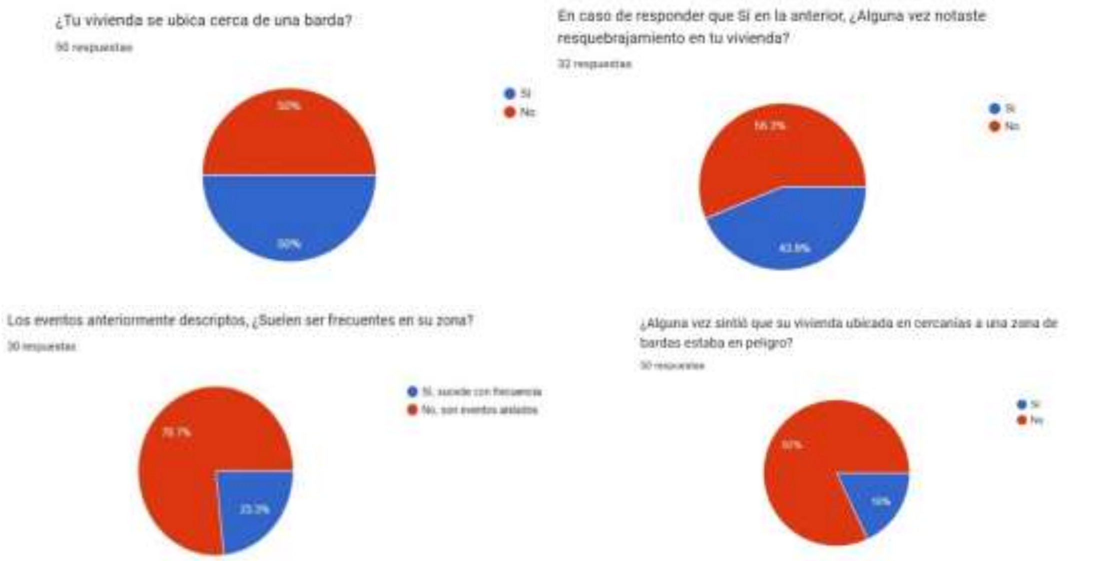
The majority of the sample (68%, $n=34$) stated they know about geology, also indicating they know what it studies and what geologists do; 26% (n=13) claimed to know about geology but without much certainty about its professional practice, and only 6% (n=3) declared having no knowledge of the area. However, the follow-up question—if they know how geology impacts urban planning—yielded an almost equal split (n=49); 49% (n=24) responded affirmatively versus 51% (n=25) who do not know about this impact. On the other hand, regarding the question about risk mitigation, only 36% (n=18) declared knowing what it is, and 64% (n=32) did not know.

Interpretation. There is a formal interest or familiarity with geology among the population (a high percentage claims to "know" the discipline), but a deficit in understanding its practical application to urban planning and, especially, in operational concepts like risk mitigation. This suggests a gap between theoretical knowledge and applied knowledge, which is relevant for designing communication and education policies in risk management.



3.6.3 Exposure, experiences, and risk perception

Regarding the proximity of homes to the "bardas", the sample is divided into equal parts: 50% of respondents (n=25) live near a "barda" and the remaining 50% do not (n=25). Of those who responded affirmatively and answered about observed damages (n= 32), 43.8% (n=14) reported having detected cracking in their homes, while 56.3% (n=18) had not. As for the perceived frequency of the described geomorphological events (n=30), only 23.3% (n=7) consider them frequent in their area, and 76.7% (n= 23) perceive them as isolated events.



However, it is surprising that when asked if they ever felt their home located near a "barda" was in danger, 82% (n=41) responded no, while only 18% (n=9) responded affirmatively (n=50). In relation to urban dynamics, a majority proportion (58%, n=29) reported that new infrastructure works are being generated near their homes, compared to 42% (n=21) who do not observe new works.

Interpretation: There is an objective exposure (50% live near "bardas"; 43.8% of those who responded registered cracking) that contrasts with a low subjective perception of danger (only 18% have felt in danger). The majority considers the episodes as isolated events, which may contribute to the low risk perception. The presence of infrastructure works (58%) may increase pressure on slopes and drainage systems if not executed with adequate geotechnical and geomorphological criteria, potentially increasing the probability of instability processes.

3.6.4 Qualitative correlation between surveys and cartography

The joint interpretation of the social results and the cartography allows for the following integrated observations38:

1. **Spatial coincidence between social exposure and high hazard/vulnerability zones**. The hazard maps (pluviometric scenarios of 2.63 and 6.75 mm/day) and the vulnerability map identify as critical sectors areas surrounding the neighborhoods with the highest density of homes close to the "bardas" (e.g., Villa Ceferino, Melipal, and Islas Malvinas). In these same areas, the survey records a significant number of homes near "bardas" and specific reports of structural damage (cracking), which validates the coherence between the spatial information and local perception/experience.

2. **Perception-hazard discrepancy**. Although the maps indicate sectors with medium-high hazard on "barda" fronts bordering urban neighborhoods, the perception of danger is generally low (82% did not feel their home was in danger). This gap indicates a latent risk of underestimation of danger by the population, which can translate into an absence of preventive measures or a delayed institutional response to events.

3. **Potential impact of infrastructure works**. The evidence of nearby works reported by 58% of respondents spatially coincides with some "barda" fronts classified with high susceptibility in the maps. If the works do not consider geology and surface/subsurface drainage management, they could increase the probability of local collapse or the activation of gravitational processes (erosion, landslides, rock falls).

4. **Cracks and repetition of events**. Although only 23.3% of a subsample perceives the events as frequent, the fact that almost half of those living next to the "bardas" have observed cracking suggests repeated episodes of stress on home infrastructure that might be under-recorded or normalized by the community.

3.6.5 Critical analysis and practical significance

- **Educational and operational gap**. The 64% lack of knowledge about risk mitigation is highly relevant: even when a significant portion knows about geology in general terms, they do not know how to translate that knowledge into concrete measures for vulnerability reduction. This hinders the adoption of preventive behaviors at the community level and informed participation in local planning processes.

- **Youth of the sample and communication channels**. The age profile (predominance of 18-25 and 25-55 years) suggests that awareness and training campaigns should prioritize digital channels, social networks, and educational activities aimed at young adults and families, with materials that link local geology to concrete actions at home and in the neighborhood.

- **Intervention priorities**. According to the map overlay and the distribution of responses, immediate interventions should prioritize: (1) neighborhoods where the location of high hazard and high social vulnerability is greatest (p. ej. Villa Ceferino and southern sectors of Bardas Soleadas); (2) sites where cracking in homes is recorded; and (3) fronts where works are being executed without apparent geotechnical control.

3.6.6 Practical recommendations derived from social results

1. **Communication and training campaigns on mitigation**: design participatory workshops and easy-to-understand materials that explain:
    - how geology influences urban planning.
    - domestic mitigation measures (drainage management, preventive crack repair, small-scale slope stabilization).
    - municipal protocols for early notification and containment.

2. **Monitoring of works and inspection of drains**: coordinate technical inspections on the reported works (58% of responses) to verify impacts on slope stability and the conduction of concentrated runoff.

3. **Registration and monitoring of structural damages**: launch a local system for reporting damages (cracking, subsidence, rock falls) to build a database that allows correlating events with precipitation, works, and changes in land use.

4. **Institutional strengthening**: promote the incorporation of geomorphological and geotechnical criteria in the approval of building permits and in territorial ordering plans.

3.6.7 Limitations and methodological considerations

- **Sample size and representativeness**. Although n=50 provides a useful first approximation, the sample does not ensure complete statistical representativeness of all neighborhoods; therefore, expanding sampling in future follow-ups is recommended.

- **Self-reporting and biases**. Responses may be subject to desirability bias or variability in the interpretation of technical concepts (e.g., "cracking" or "mitigation").

- **Heterogeneity of n per question**. Some questions have different response sizes (n=49, 32, 30), which requires analyzing percentages and absolute values with caution.

3.6.8 Integrated synthesis

The overlap between the hazard/vulnerability maps and the survey results allows affirming that there is consistency between the mapped physical risk and local experience, although it is not always translated into a perception of danger64. This gap between objective risk and perception suggests the need to prioritize technical dissemination actions and local governance mechanisms that integrate the community in risk reduction measures65. In particular, the areas where high hazard and high social vulnerability coincide must be considered priority action zones: structural inspections, works control, and educational campaigns on mitigation and emergency protocols.

4. DISCUSSION

The results obtained show a latent geomorphological risk situation on the "bardas" (cliffs/bluffs) of Neuquén, derived both from the natural conditions of the terrain and from the increasing anthropic occupation of unstable sectors. The combination of steep slopes, unconsolidated materials, and active erosive processes constitutes a favorable scenario for the occurrence of rock falls, shallow landslides, and regressive slope erosion. However, the social data reflect that a large part of the population does not fully perceive the magnitude of these risks, which increases the general vulnerability of the system.

In terms of perception, respondents recognize the existence of natural hazards, but their level of concern and preparation for them is limited. This suggests a gap between technical knowledge and social perception of risk, common in urban areas expanding into fragile natural environments. This disconnection may be due to a lack of accessible information, the normalization of the landscape (where the abrupt relief is perceived as part of the everyday environment), and the absence of sustained municipal risk communication policies.

Faced with this situation, the results allow for several lines of action aimed at the prevention and comprehensive management of geomorphological risk:

4.1 Territorial ordering and urban planning It is essential to incorporate the hazard and vulnerability maps developed in this work into local planning instruments. This would allow for restricting urban expansion onto high-hazard sectors, especially on the active fronts of the "bardas", and guiding growth towards areas with lower slopes and greater geotechnical stability. Likewise, it is recommended to establish buffer zones at the foot of the slopes, avoiding new constructions in sectors of debris accumulation or evidence of active erosion.

4.2 Risk education and communication The low level of knowledge about preventive measures reveals the need for environmental education programs and community workshops focused on understanding the landscape and its associated risks. Dissemination can be carried out through local media, neighborhood centers, and schools, promoting citizen participation and fostering a culture of prevention. Simple actions, such as signaling unstable zones or creating safe trails for recreational transit, would contribute to reducing exposure.

4.3 Infrastructure and control of erosive processes In the most critical sectors (Villa Ceferino, Melipal, and Islas Malvinas), it would be advisable to implement slope control and stabilization works, such as surface drains, retaining walls, and reforestation with native species that improve soil cohesion. These measures must be accompanied by periodic monitoring using geospatial techniques, utilizing multi-temporal comparisons of DEMs and aerial photographs to detect retreats of the "barda" fronts.

4.4 Institutional strengthening and risk management The approach to geomorphological risk must be integrated into municipal civil defense and environmental management plans. The creation of a local registry of geomorphological events (landslides, rock falls, erosion) is recommended, which would allow for consolidating historical information and facilitating decision-making. Articulation between universities, municipalities, and technical bodies (such as Civil Defense and Citizen Protection) will favor a coordinated and sustainable response to possible emergencies.

5. CONCLUSION

The comprehensive study developed on the "bardas" (cliffs/bluffs) north of the city of Neuquén allowed for an understanding of the complex interaction between natural geomorphological processes, recent urban dynamics, and the social perception of risk in an environment characterized by its high environmental fragility. The conjunction of physical, cartographic, and social evidence demonstrates that the area presents a latent geomorphological risk situation, where human occupation overlaps with unstable relief, conditioned by steep slopes, unconsolidated materials, and active erosive processes. This scenario, added to accelerated and often geopolitically unplanned urban growth, creates conditions conducive to the occurrence of mass removal phenomena, rock falls, and regressive erosion.

From the geomorphological characterization, it was observed that the fronts of the "bardas", especially in the sectors adjacent to the Villa Ceferino, Melipal, Bardas Soleadas, and Islas Malvinas neighborhoods, concentrate the steepest slopes and evidence of active erosion. The dominant lithology—sandy-silty with interbedded tuff levels—reinforces the susceptibility of the slopes to water saturation or additional loads derived from works and infrastructure. The hazard maps developed for different rainfall scenarios reflect a high recurrence of critical zones, which highlights the need to establish construction restrictions in the sectors of greatest instability. Similarly, the vulnerability analysis shows that the greatest exposure corresponds to areas where deficiencies in drainage infrastructure, precarious construction, and direct proximity to the slopes combine, factors that amplify the risk in the face of geomorphological events.

The integration of spatial information with social results constitutes one of the central contributions of this work. Cross-referencing surveys with cartography confirmed that the zones of greatest hazard coincide with those where the population manifests a low perception of risk, suggesting the existence of a dangerous dissociation between objective physical risk and subjective perception of it. Although a high percentage of respondents claim to know about geology, operational knowledge about its practical application—particularly in risk mitigation and urban planning—is limited. This finding highlights the gap between technical-scientific knowledge and social knowledge, a recurring problem in urban contexts that expand onto naturally fragile landscapes. Consequently, education and risk communication emerge as strategic and indispensable components for reducing vulnerability.

The youth of the surveyed group (predominance of people between 18 and 55 years old) constitutes an opportunity to implement environmental and geoscientific education programs aimed at key population segments in family and community decision-making. The use of digital tools, social networks, and neighborhood participation spaces can contribute to improving the understanding of geomorphological processes and fostering preventive practices, such as the early repair of cracks, adequate channeling of runoff, and reporting of works carried out without technical control.

From a territorial point of view, the results highlight the urgency of incorporating geomorphological and geotechnical criteria into the urban ordering instruments of the municipality of Neuquén. The inclusion of hazard and vulnerability maps in master plans would allow for defining non-buildable zones, buffer corridors, and mandatory monitoring areas. In particular, the fronts of the "bardas" must be considered as restriction or special management zones, where human intervention is conditioned by prior studies of slope stability, drainage design, and geotechnical impact assessment. These measures must be complemented with control works—retaining walls, drains, revegetation with native species—and a continuous multi-temporal monitoring system to evaluate the evolution of erosion fronts through comparisons of digital terrain models, aerial photographs, and precipitation data.

The analysis also underscores the need to strengthen institutional governance and intersectoral risk management. The articulation between the municipality, provincial technical bodies, universities, and neighborhood organizations is essential to implement comprehensive and sustained management of geomorphological risk. The creation of a local registry of events (rock falls, landslides, erosion, cracks in homes) would allow for building a historical database to serve as input for preventive planning and evidence-based decision-making.

In social terms, the research revealed that, although 43.8% of residents near the "bardas" reported structural damage (such as cracking in their homes), only 18% stated they had felt in danger due to their location. This contrast shows a minimized perception of risk, possibly related to habituation to the environment or a lack of information about the genesis of these processes. Such a gap constitutes one of the most important challenges for risk management in Neuquén, as underestimating the danger can delay response actions or limit citizen demands on authorities.

Consequently, risk reduction on the Neuquén "bardas" requires combined technical, educational, and political actions, among which the following stand out:

- Implementation of urban planning policies based on geomorphological evidence, avoiding expansion onto sectors of high slope or active erosion.
- Creation of awareness and community education campaigns that translate geoscientific knowledge into concrete, everyday actions.
- Establishment of inspection and maintenance protocols for works to ensure that new urban developments incorporate adequate drainage and stabilization measures.
- Promotion of citizen participation in environmental monitoring, through damage reporting applications, continuous surveys, and participatory diagnostic workshops.

Finally, the work demonstrates that the integration between the physical and social components of risk allows for a more complete understanding of the territorial problem. The adopted approach—which combines geomorphological analysis, cartographic modeling, and perceptual evaluation—constitutes a replicable tool for other urban sectors in Patagonia and Argentina where the interaction between relief and urbanization generates similar situations.

In summary, the geomorphological risk on the "bardas" north of Neuquén should not be interpreted as an inevitable threat, but as a manageable process through the application of technical knowledge, responsible planning, and informed citizen participation. Recognizing geology as a structural element of the territory and not as a mere physical backdrop is the first step towards a safer, more resilient, and sustainable city.

REFERENCES

Agboola, G., Hashemi Beni, L., Elbayoumi, T., & Thompson, G. (2024). Optimizing landslide susceptibility mapping using machine learning and geospatial techniques. Ecological Informatics, 81, 102583. https://doi.org/10.1016/j.ecoinf.2024.102583.

Cascini, L., Bonnard, C., Corominas, J., Jibson, R., & Montero-Olarte, J. (2005). Landslide hazard and risk zoning for urban planning and development. In Proceedings of the International Conference on Landslide Risk Management (pp. 199–239).

Chen, F., Lin, H., Zhang, Y., & Lu, Z. (2012). Ground subsidence geo-hazards induced by rapid urbanization: Implications from InSAR observation and geological analysis. Natural Hazards and Earth System Sciences, 12(3), 935–942. https://doi.org/10.5194/nhess-12-935-2012.

Cui, Y., Cheng, D., Choi, C. E., Jin, W., Lei, Y., & Kargel, J. S. (2019). The cost of rapid and haphazard urbanization: Lessons learned from the Freetown landslide disaster. Landslides, 16(6), 1167–1176.