

Balancing risk and heritage: Geospatial assessment of tourism vulnerability in volcanic landscapes of Arequipa, Perú

Equilibrando riesgo y patrimonio: Evaluación geoespacial de la vulnerabilidad del turismo en paisajes volcánicos de Arequipa, Perú

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ABSTRACT

This study explores the relationship between geodynamic hazards and community-based tourism in the Sillar Quarries of Añashuayco, Arequipa, Peru. Through GIS-based mapping, we assessed volcanic activity, fluvial events, and mass movements affecting the tourism infrastructure. Data from INGEMMET, field mapping, and tourism records revealed that while volcanic ashfall poses a moderate threat, sudden rockfalls from intensive quarrying are the most immediate risk. Despite receiving over 350 tourists daily, the area lacks formal contingency plans or structural safety measures. Comparative cases from Indonesia and New Zealand stress the urgency of geotechnical assessments, signage, and evacuation routes. The study highlights the importance of integrated risk governance to ensure safety while preserving geological heritage and supporting sustainable community tourism.

Keywords: *Geotourism, risk mapping, Community-based tourism, territorial planning, tourism resilience, volcanic hazard assessment.*

RESUMEN

Este estudio explora la relación entre amenazas geodinámicas y el turismo comunitario en las Canteras de Sillar de Añashuayco, Arequipa, Perú, a través de una cartografía basada en sig, se evaluó la actividad volcánica, los eventos fluviales y los movimientos en masa que afectan la infraestructura turística. Los datos del ingemmet, el mapeo de campo y los registros turísticos revelaron que, si bien la caída de ceniza volcánica representa una amenaza moderada, los desprendimientos de rocas causados por la explotación intensiva de las canteras constituyen el riesgo más inmediato. A pesar de recibir más de 350 turistas diarios, la zona carece de planes de contingencia formales o medidas estructurales de seguridad. Casos comparativos de Indonesia y Nueva Zelanda subrayan la urgencia de realizar evaluaciones geotécnicas, instalar señalización y establecer rutas de evacuación. El estudio resalta la importancia de una gobernanza del riesgo integrada para garantizar la seguridad, preservar el patrimonio geológico y apoyar un turismo comunitario sostenible.

Palabras clave: Geoturismo, mapeo de riesgos, turismo comunitario, ordenamiento, territorial, resiliencia turística, evaluación del riesgo volcánico.

INTRODUCTION

The Canteras del Sillar, located in the Añashuayco ravine in the district of Cerro Colorado (Arequipa, Peru), represent a site of high cultural, economic, and geological value. However, the extractive and tourism activities carried out in the area coexist with multiple natural hazards that have sparked ongoing debate among residents, visitors, and local authorities. This analysis proposes a classification of three main categories of geohazards: volcanic activity (ashfall, pyroclastic material), fluvial events (floods and debris flows), and mass movements. While fluvial and volcanic events pose significant threats, their gradual and non-imminent nature allows for the development of mid-term mitigation strategies such as evacuation protocols, geological monitoring, and public awareness campaigns (Susanto et al., 2024; Copernicus Editors, 2022). In contrast, landslides resulting from the intensive exploitation of sillar stone require immediate and sustained intervention due to their sudden and potentially fatal nature, as evidenced in similar contexts such as New Zealand's Whakaari volcano (Thompson, 2023).

This study draws on international experiences in tourism areas with similar geophysical conditions to extract valuable lessons for risk management and to support a sustainable coexistence between tourism activities and territorial safety. In sites such as Mount Semeru (Indonesia), Mount Anak Krakatau, and Mount Merapi, effective strategies have been developed to protect both workers and visitors, including safety regulations, risk zone signage, and spatial zoning (Putra et al., 2023; Suhud et al., 2024; Muktaf et al., 2023). The Sillar Route tourist circuit, located in the district of Cerro Colorado, exemplifies how geological and cultural heritage can be integrated into sustainable local development. The quarries, formed from volcanic tuff resulting from eruptions of the Chachani volcano, have historically provided the livelihood of numerous artisan families who carve sillar stone for both construction and artistic purposes.

According to the final report of the Inclusive Development of the Sillar Route project—funded by Fondo Empleo and executed by the Center for Research, Education, and Development (CIED)—451 direct beneficiaries were identified in 2015, including 325 quarry workers and 125 artisan stonecutters involved in sillar extraction and carving (Fondo Empleo & CIED, 2015). This group has played a key role in preserving tradition while opening new economic opportunities related to tourism. Among them, 20 individuals have received training as tour guides to lead interpretive tours

through the ravines, carving workshops, and sculpture areas. Additionally, approximately five formal tour operators offer services within the circuit, including guided tours, transportation, and food services (Fondo Empleo & CIED, 2015). Tourist flow in the area has increased notably, with average annual visits rising from 1,200 to 2,640 a 120% growth following the implementation of the Sillar Route. While official updated figures for 2025 are not yet available, municipal reports indicate greater tourism activity during holidays and cultural events, such as carving competitions and large-scale sillar exhibitions promoted by the Cerro Colorado District Municipality (Municipalidad de Cerro Colorado, 2019).

Although moderate, this growth demonstrates the potential of emerging geotourism sites as drivers of local economic development particularly when linked to community participation, ancestral knowledge valorization, and sustainable tourism promotion strategies (Leoni & Boto García, 2023; Dewi et al., 2023). However, this potential is constrained by a persistent conflict between the site's cultural-economic value and the perception of risk held by segments of the local population and municipal authorities. In the specific case of the Añashuayco Sillar Quarries, the identification of geodynamic threats such as landslides, debris flows, and slope instability has led local governments to adopt restrictive stances. Although this risk perception is grounded in technical studies, it has been used to justify delaying the formalization of artisanal labor, thereby preventing quarry workers from accessing licenses, basic municipal services, or productive support programs (Applied Volcanology Group, 2023; Ristiano et al., 2024).

As a result, artisans continue to operate informally, without labor protections, access to technological improvement programs, or full integration into sustainable tourism circuits. The lack of a clear municipal legal framework also limits public and private investment in safety infrastructure, signage, and complementary services that could enhance the tourist experience.

The absence of political will to initiate a risk-based territorial formalization process perpetuates a paradox: while the Sillar Route is officially recognized as a site of tourism heritage, its consolidation is hindered by the very risks that define it. Overcoming this contradiction requires coordinated intervention among local authorities, organized artisans, and specialized technical agencies, with a focus on ensuring safety without undermining the development potential of this traditional activity.

METHODOLOGY MATERIALS AND METHODS

This study adopts a qualitative empirical design with geospatial integration, aimed at evaluating geological hazards and their relationship with tourism and artisanal activities in the Canteras del Sillar of Añashuayco, Arequipa, Peru. The research seeks to identify and spatially correlate three types of geodynamic threats volcanic activity, fluvial events, and mass movements using GIS-based tools and validated public geospatial datasets. The methodological approach builds on comparable studies concerning risk mapping and tourism in active volcanic zones.

Data sources and spatial inputs

Geospatial data were obtained from the official portal of the Geological, Mining, and Metallurgical Institute of Peru (INGEMMET) via the GEOCATMIN viewer (<https://geocatmin.ingemmet.gob.pe>). The following thematic layers were used:

- Fluvial flood susceptibility (SERV_IMG_SUSCEP_INUN_FLUVIAL)
- Base cartography (WGS84) (SERV_CARTOGRAFIA_BASE_WGS84)
- Mass movement susceptibility (SERV_IMG_SUSCEP_MOV_MASA)
- Volcanic hazard zones (SERV_VOLCANES)

All raster and vector data were downloaded at a 1:100,000 scale and processed in accordance with official technical specifications.

Gis analysis

Spatial analysis was conducted using ArcGIS 10.4 (ArcMap module). Layer overlay techniques were applied to identify convergence zones between geological hazards and the delineated polygon of the Añashuayco tourist circuit. The volcanic hazard analysis focused on ashfall and pyroclastic flows, based on known eruptive parameters of the Misti volcano. Comparative exposure models were developed using case studies from Mount Semeru (Indonesia) and Taal Volcano (Philippines). Hydrological risk was modeled through slope and flow accumulation analyses to identify potential debris flow (huaico) pathways. Mass movement susceptibility was assessed through a morphostructural analysis of quarry slopes, cross-referenced with benchmark studies from Whakaari and Merapi volcanoes.

Document analysis and contextual validation

A review of peer-reviewed scientific literature (2019–2024) on tourism in volcanic risk zones and hazard perception was integrated to contextualize the spatial findings. Regulatory and institutional documents were also analyzed, including the Disaster Risk Reduction Plan of the Province of Arequipa (2023–2025) and reports from the Sillar Route Program by Fondo Empleo–CIED. These sources supported both the spatial delineation and the socioeconomic characterization of local stakeholders.

Study area delimitation and exposure matrix

The study area was delineated using official maps, satellite imagery, and field data provided by municipalities and artisan registries. This polygon was validated through cross-comparison with topographic layers and municipal cadastral records. Subsequently, an exposure matrix was constructed, linking hazard type (volcanic, fluvial, mass movement) to the functional zones of the tourist circuit (extraction areas, tourist paths, artisan housing). This matrix allowed for the prioritization of mitigation actions based on the immediacy and severity of the identified threats.

RESULTS

For the development of the analysis, the primary input used was the SERV_CARTOGRAFIA_BASE_WGS84 file, downloaded directly from the official website of the Geological, Mining, and Metallurgical Institute of Peru (INGEMMET). This file was processed and analyzed using ArcMap 10.4 software and served as the base map for overlaying thematic layers relevant to each evaluated scenario. The integration of these layers enabled a detailed and contextualized spatial analysis for each case study. An important consideration is that the volcano with potential impact on the Canteras del Sillar in Añashuayco is Misti Volcano, which is officially classified as active by INGEMMET.

Volcanic activity: indirect risks and mid-term planning

Although Misti Volcano is located approximately 15 kilometers from Añashuayco, its activity has the potential to disperse fine ash, which can impair respiratory health and reduce environmental visibility. This type of impact was documented during the 2020 eruption of Taal Volcano in the Philippines, where ashfall disrupted flights, forced hotel closures, and suspended tourist activities for over a week (Philippine Journal of Disaster Management, 2022). Studies such as Erfurt (2022) emphasize that volcanic destinations

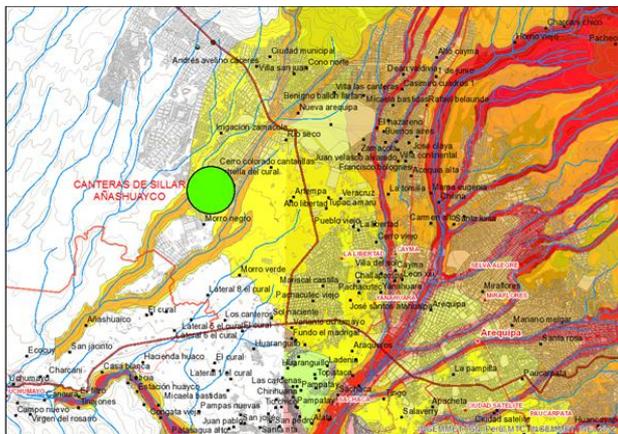
should incorporate public health protocols, including the distribution of N95 masks and tourist education campaigns. Similar measures were implemented at Mount Anak Krakatau, where tour operators established safe routes and designated regrouping areas (Suhud et al., 2024). These examples suggest that while volcanic activity poses a moderate-frequency threat, its associated risk can be substantially mitigated through anticipatory land-use planning, satellite-based monitoring, and coordinated multisectoral efforts.

For the volcanic hazard analysis, the SERV_VOLCANES dataset was used, which provides data on pyroclastic flows and ash dispersion.

a) Pyroclastic Flow

The pyroclastic flow map (Fig. 1) shows that the Añashuayco quarries lie outside the highest-risk zone (intense red), but within a moderate-risk zone, potentially due to the presence of natural channels capable of directing volcanic materials. The primary pyroclastic flow path associated with Misti Volcano trends east and southeast; however, a branch of this flow corridor extends northward, approaching the Añashuayco area. This indicates an indirect risk in the event of a major eruption.

Figura 1. Pyroclastic Volcanic Hazard Map – Añashuayco Sillar Quarries.



b) Ashfall

According to the ash hazard maps Low Ashfall Scenario (Fig. 2) and High Ashfall Scenario (Fig. 3) the Añashuayco area falls within the projected ash dispersion zone in both cases.

- Under low-intensity conditions, the area is expected to receive approximately 1–2 cm of ash.
- Under high-intensity conditions, ash deposits may exceed 3–5 cm.

The accumulation of volcanic ash in the area could result in several impacts:

- Disruption of extractive and commercial activities.

- Respiratory health risks for quarry workers.
- Damage to machinery and infrastructure.

Figura 2. Low-Intensity Ashfall Hazard Map – Añashuayco Area.

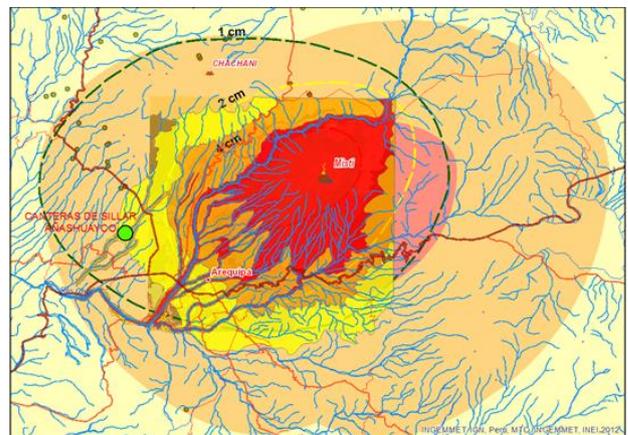
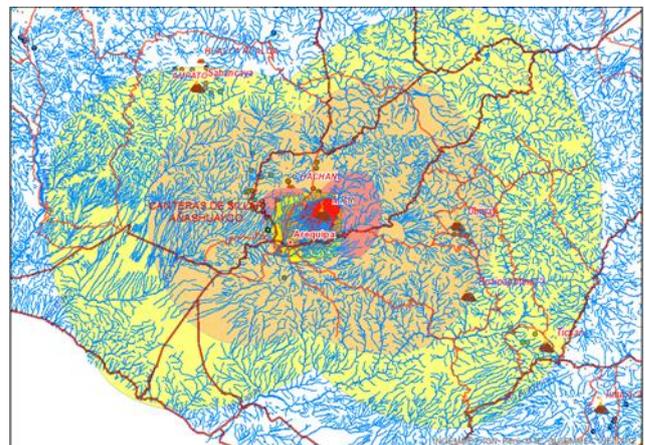


Figura 3. High-Intensity Ashfall Hazard Map – Añashuayco Area.



Fluvial Events: Cyclical but Predictable Hazards

Heavy rainfall affecting the northern cone of Arequipa activates ravines such as Añashuayco and San Lázaro, generating debris flows that carry sediments and pose risks to both workers and tourists (PREDES, 2020). This pattern is comparable to that observed in volcanic areas of Indonesia, such as Semeru and Merapi, where tourist routes must be temporarily closed during periods of intense rain to prevent unnecessary exposure (Muktaf et al., 2023). Experiences from Mount Etna (Italy) also demonstrate how the installation of piezometric and rainfall sensors can trigger early warning systems along hiking trails (Copernicus Editors, 2022). These tools not only alert authorities but also enable controlled evacuations without severely affecting economic activity.

For the fluvial hazard analysis, the dataset SERV_IMG_SUSCEP_INUN_FLUVIAL was used, which provides a susceptibility assessment for flood-related events.

According to Fig. 4, the map uses blue and green tones to indicate flood susceptibility levels:

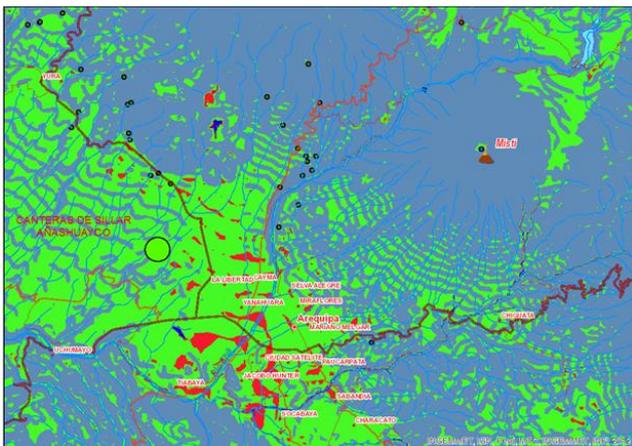
- Dark blue represents areas of high susceptibility.
- Green indicates low to negligible susceptibility.

The Añashuayco area (marked with a green circle) falls within a green-yellow zone, which suggests:

- Low fluvial flood susceptibility, likely due to its location on elevated terrain or sediment terraces not intersected by primary waterways.
- No direct presence of major rivers that would increase hydrological risk.

However, secondary drainage channels have been identified in the area, which may become active during episodes of intense rainfall or hyperconcentrated flows.

Figura 4. Fluvial Flood Susceptibility Map – Añashuayco Area.



Mass movement susceptibility

For the analysis of mass movement risk, the dataset SERV_IMG_SUSCEP_MOV_MASA was employed. This dataset provides a susceptibility assessment for landslides, debris flows, and rockfalls.

Fig. 5 displays a hazard map highlighting zones at risk of mass movement, with the following color codes:

- Red and orange: High susceptibility.
- Yellow: Moderate susceptibility.
- Green and beige: Low to negligible susceptibility.

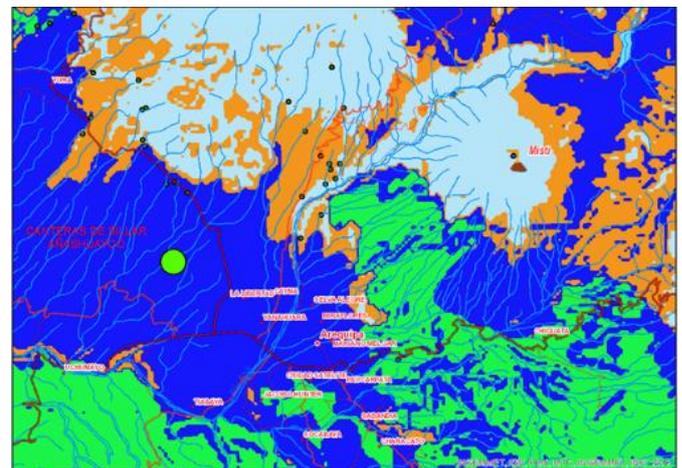
The Añashuayco area is located within a yellow zone, indicating moderate susceptibility. This condition is likely related to:

- Slopes modified by extractive quarrying activity.
- Unvegetated terrain lacking slope stabilization measures.

Additional aggravating factors in the area include:

- Steep slopes.
- Continuous excavation within the quarry sites.
- Presence of unconsolidated volcanic materials (tuff/sillar).
- Limited intervention in surface water drainage infrastructure.

Figura 5. Mass movement susceptibility map – Añashuayco Area.



Quantifying the development of Community-based tourism in the Canteras del Sillar, Arequipa

The Canteras del Sillar, located in the Añashuayco ravine (Cerro Colorado district, Arequipa, at altitudes between 2,400 and 2,600 meters above sea level), have undergone a significant transformation toward community-based tourism. This transition was consolidated through the “Inclusive Development of the Sillar Route” program (2012–2015), implemented by Fondo Empleo and the Center for Research, Education and Development (CIED), which combined heritage valorization with income generation for the local population (see Table 1).

Artisan production

- The project directly benefited 530 individuals, including 325 block cutters and 205 artisan operators working in family-owned workshops.
- A 33.5% increase in monthly block production was reported, rising from 200 to 267 blocks per artisan.
- A parallel study identified 200 active sillar cutters, with a gender distribution of 92.5% male and 7.5% female, and an age range from 11 to 90 years.

Tourist flow

- In 2014, the site recorded an average of 399 visitors per month (approximately 4,788 visitors per year), with the participation of 12 travel agencies and 5 formal tour operators.
- By 2023, the average had risen to 350 visitors per day, reaching up to 500 on weekends and holidays, according to the Association of Sillar Cutters and Artisans.

Table 1. Key Statistics from the “Inclusive development of the Sillar Route” Program (2012–2015) implemented by Fondo Empleo and CIED.

Indicator	Quantification
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Active block cutters	200 individuals
Trained interpreter-artisans	20 artisans
Registered tours operators	5 formal compaies
Visitors (2014)	4,788 per year (=399 per month)

The results reflect a successful shift from traditional quarry use to a community-based tourism model, with positive impacts on local employment, geocultural heritage recognition, and social cohesion. The active participation of artisans as interpreters and hosts has been key to strengthening this sustainable development strategy.

DISCUSSION

Volcanic risk and the sustainability of tourism services in the Canteras del Sillar of Añashuayco

The development of community-based tourism at the Canteras del Sillar, located in the Añashuayco ravine, has emerged as a successful model of integration between geological heritage, cultural identity, and economic opportunity benefiting over 500 individuals directly (Fondo Empleo & CIED, 2015). However, this progress must be critically examined in the context of the geodynamic activity of Misti Volcano, situated just 15 km from the tourist site.

Although volcanic hazard maps developed by INGEMMET indicate that the quarries lie outside the highest-risk zone for pyroclastic flows, they remain within a moderate hazard zone for ashfall (Municipalidad Provincial de Arequipa, 2022; MINAM, 2015).

Spatial analysis using the SERV_CARTOGRAFIA_BASE_WGS84 dataset, along with low- and high-intensity ashfall layers, confirms that Añashuayco could receive 1 to 5 cm of ash in the event of a VEI 2 or 3 eruption. Such an event could temporarily affect respiratory health, visibility, and destination operations. In this context, recent literature emphasizes that the sustainability of tourism in active volcanic zones depends not only on technical monitoring, but also on visitors' perception of risk (Erfurt, 2022; Susanto et al., 2024). Case studies such as the Taal Volcano (Philippines) (Philippine Journal of Disaster Management, 2022) and Mount Semeru (Indonesia) (Putra et al., 2023) demonstrate that moderate-intensity eruptions can halt tourism activity for days or weeks, severely impacting local economies. However, studies also agree that the implementation of contingency protocols and proactive communication strategies can substantially reduce these negative effects (Ristianto et al., 2024; Suhud et al., 2024).

The experience at Mount Anak Krakatau illustrates how training tourist interpreters in risk management, installing signage, establishing safe zones, and making evacuation plans publicly available can build trust among visitors (Suhud et al., 2024). In Añashuayco, such components are still incipient, but could be integrated into the existing community-based tourism model, particularly given the presence of a well-established network of local guides and interpretive trails (Boza González, 2015; Fondo Empleo & CIED, 2015). On the other hand, studies such as Muktaf et al. (2023), focusing on tourism operators near Mount Merapi, highlight that small tourism enterprises in hazard-prone areas are highly vulnerable to abrupt service interruptions. In this regard, the five formal tour operators currently active in Añashuayco should be incorporated into risk monitoring networks, as well as receive training and technical support from institutions such as CENEPRED and the Sub-Directorate of Civil Defense.

Tourist services in Añashuayco and their vulnerability to flood susceptibility

According to the study by PREDES (2020), the Añashuayco ravine alongside others in the northern cone of Arequipa presents a high risk of sudden floods and debris flows (huaicos), particularly during the rainy season. Although this cyclical pattern is predictable, it constitutes a real threat to the safety of tourists and workers, as well as the continuity of tourist routes. Cartographic analysis based on the SERV_IMG_SUSCEP_INUN_FLUVIAL dataset shows that most

of the tourist zone lies within areas of low to moderate susceptibility (green-yellow zones), likely protected by elevated alluvial terraces. However, secondary drainage channels have been identified in the area that may become active during heavy rainfall events, posing indirect risks to tourist infrastructure and artisanal workshops located in unconsolidated terrain (Municipalidad Provincial de Arequipa, 2022).

International experiences support the integration of both structural and non-structural mitigation measures. For example, in similar contexts such as the slopes of Mount Merapi (Indonesia), systems have been implemented that include rainfall monitoring, community alarm systems, and seasonal evacuation protocols, aimed at protecting both tourism activity and visitor safety (Muktaf et al., 2023). Similarly, studies in European hazard-prone zones show that evacuation effectiveness significantly increases when supported by adequate channeling infrastructure and early warning systems based on pluviometric sensors (Copernicus Editors, 2022). In Añashuayco, although tourism flow reached an average of 350 daily visitors in 2023, there is currently no public evidence of a contingency plan specifically designed for extreme rainfall, which heightens operational vulnerability. The absence of such protocols compromises not only safety, but also the perceived reliability of the destination a critical factor for the sustainability of geotourism (Erfurt, 2022). Moreover, the impacts of sudden flooding extend beyond human or material losses, often resulting in social and economic disruptions, especially when livelihoods depend on a steady flow of visitors (Boza González, 2015). Therefore, the following measures are recommended:

- Temporary relocation of workshops located in runoff-prone areas.
- Design of alternative interpretive routes in higher-elevation zones.
- Implementation of preventive closure protocols during heavy rainfall periods.

The Disaster Prevention and Risk Reduction Plan for the Province of Arequipa (2023–2025) clearly identifies these threats and proposes actionable strategies that can be operationalized by the Cerro Colorado District Municipality, in coordination with tour operators and artisan associations (Municipalidad Provincial de Arequipa, 2022; Municipalidad Distrital de Cerro Colorado, 2018).

[Tourist services in Añashuayco and their vulnerability to mass movements](#)

According to the Mass Movement Susceptibility Map (SERV_IMG_SUSCEP_MOV_MASA), the Añashuayco ravine is classified as a moderate susceptibility zone (yellow). This condition is attributed to the presence of steep slopes, erodible soils, ongoing extractive activity, and limited vegetation cover (MINAM, 2015; Municipalidad Provincial de Arequipa, 2022). Additionally, excavation without slope stabilization measures has increased the risk of rockfalls and partial slope collapses. This scenario is particularly critical given that the guided tourist routes extend over 2,200 meters through exposed areas, and the average daily visitor count has exceeded 350 people in recent years (Fondo Empleo & CIED, 2015). The combination of high foot traffic and fragile terrain elevates the risk of direct impacts in the event of a sudden landslide. Although mass movement events in Añashuayco do not occur frequently, their activation may be triggered by intense rainfall, seismic activity, or progressive weakening of the terrain. These hazards should therefore be treated as latent threats, with a seasonal or cumulative occurrence profile, requiring moderate response times to mitigate impacts (PREDES, 2020).

Comparable experiences in mountain and volcanic tourism sites, such as Mount Etna or Mount Vesuvius, demonstrate that the implementation of geotechnical monitoring systems, exclusion zone signage, and predesigned evacuation routes can effectively reduce visitor exposure without compromising the tourism experience (Copernicus Editors, 2022). In the case of Añashuayco, these measures could be implemented through collaboration between the district municipality, Civil Defense authorities, and tour operators. Furthermore, Erfurt (2022) emphasizes that perceptions of safety in geotourism destinations are shaped not only by actual risk, but also by visible preparedness and response capacity. Therefore, training tourist interpreters and developing visual emergency protocols could help maintain visitor trust without detracting from the destination's appeal. Cases such as Mount Merapi in Indonesia reveal that small tourism operators in risk-prone areas are particularly vulnerable to service interruptions, reinforcing the idea that preventive planning is also an economic sustainability strategy (Muktaf et al., 2023).

[Rockfalls in Añashuayco and their implications for tourism development](#)

The process of productive reconversion of the Canteras del Sillar into a community-based tourism destination has enabled the consolidation of a model grounded in cultural and geological heritage, benefiting over 500 individuals, including stone cutters and artisan operators (Fondo Empleo & CIED, 2015). However, this potential faces a critical and immediate

threat: rockfalls associated with extractive activities, which constitute one of the most significant risks for both workers and visitors. According to the Disaster Risk Prevention and Reduction Plan of the Province of Arequipa (Municipalidad Provincial de Arequipa, 2022), active quarry fronts have been identified without structural support, loose material accumulation, and the absence of containment systems such as wire mesh or passive barriers. This situation is exacerbated by the vertical morphology of extraction faces and the manual, low-tech nature of quarrying operations.

Block detachment events are not only common in unstabilized quarry systems, but also represent a high-priority threat due to their sudden onset and minimal response time. As Erfurt (2022) notes, geotourism destinations with latent risks must be equipped with immediate safety protocols, since evacuation time in the event of gravitational collapse is limited, and the probability of fatality is high.

The case of Whakaari (New Zealand) demonstrates that even under low alert levels, the absence of clear planning and designated safe zones can have fatal consequences, as was the case with the death of 22 tourists in 2019 (Thompson, 2023). Although Añashuayco does not face active volcanic threats, the structural risk caused by anthropogenic activity shows important parallels in terms of vulnerability and exposure. In this regard, practices implemented in Mount Semeru offer valuable lessons in risk reduction, including:

- Precise zoning,
- Differentiated signage,
- Periodic geotechnical evaluations, and
- Most importantly, separate pathways for tourists and artisanal quarry workers (Putra et al., 2023).

In Añashuayco, where daily visitor numbers exceed 350, the close physical proximity between extraction sites and interpretive routes dangerously increases the likelihood of accidents. Ristiano et al. (2024) emphasize that visitor protection in high-risk destinations must be supported by clear local regulations, staff training, and continuous monitoring. While tourist interpreters in Añashuayco have received training on cultural and technical topics, there are no reports of specific training in evacuation protocols or first aid in the event of structural collapse, representing a weakness in current risk management practices. Moreover, it is important to note that over 92% of stone cutters are working-age men, and the collapse of quarry fronts threatens not only tourist safety, but also the economic continuity of families directly dependent on extraction (Boza González, 2015). Failure to

implement corrective measures could lead to irreversible social and heritage-related consequences.

[Viability of tourism in the Canteras del Sillar Amid geodynamic risks: Toward Sustainable and safe management](#)

The tourist circuit of the Canteras del Sillar in Añashuayco represents a strategic opportunity to diversify the local economy, enhance geological heritage, and strengthen the cultural identity of the Cerro Colorado district. However, the coexistence of geodynamic hazards including volcanic activity, fluvial events, and mass movements poses real challenges to the sustainability of tourism services in the area. In response, certain municipal authorities have adopted a restrictive stance, delaying formalization processes and limiting both public and private investment. Nevertheless, international case studies and recent research demonstrate that these risks can be effectively managed through a resilient tourism approach supported by integrated mitigation strategies. Regarding volcanic risk, although the Canteras lie outside the direct pyroclastic impact zone of Misti Volcano, they are moderately exposed to ashfall, with projections of up to 5 cm in medium-scale eruption scenarios (Municipalidad Provincial de Arequipa, 2022).

As Erfurt (2022) argues, such risks, rather than being disqualifying, can be incorporated into health and safety protocols, including mask distribution, eyewash stations, and first-aid training for tourist guides. Experiences from Mount Anak Krakatau show that the implementation of signage, regrouping zones, and satellite monitoring systems significantly improves the perceived safety among tourists and operators (Suhud et al., 2024).

Regarding fluvial events, although susceptibility maps from INGEMMET indicate low to moderate hydrological vulnerability in Añashuayco, this may intensify during seasonal extreme rainfall (PREDES, 2020). To mitigate such risks, successful models like those used on the slopes of Mount Vesuvius including groundwater sensors, community alert systems, and elevated evacuation routes can be adapted to minimize exposure without interrupting the tourism experience (Copernicus Editors, 2022). In this context, the Cerro Colorado District Municipality could develop a rainfall monitoring network, designate alternative routes that avoid runoff-prone areas, and establish temporary closure plans during the rainy season, as practiced at Mount Merapi (Muktaf et al., 2023). The most immediate and lethal hazard in the area is related to rockfalls caused by intensive sillar extraction. The lack of slope stabilization, protective barriers, or wire mesh along active quarry fronts poses an unacceptable risk to the more than 350 daily visitors on interpretive trails (Fondo Empleo & CIED, 2015).

According to Thompson (2023), sudden collapses, such as the Whakaari eruption in New Zealand, can be prevented through exclusion zone demarcation, regular geotechnical evaluations, and professionalization of tourism operators. In Añashuayco, such measures are not only necessary they are urgent. The municipality, in coordination with Civil Defense authorities and artisan associations, must finance and implement basic containment infrastructure and establish separate routes for tourism and extractive activity, as has been done at Mount Semeru (Putra et al., 2023). From a regulatory perspective, local authorities must shift their mindset: risk should no longer be seen as a justification for restricting tourism development but as a factor to be managed proactively. The literature indicates that tourism sustainability in hazard-prone areas depends not on the absence of danger, but on the presence of strong, reliable, and visible response capacity (Erfurt, 2022; Ristiano et al., 2024). Therefore, the implementation of a comprehensive risk management plan for tourism in Añashuayco is proposed, including:

- Mandatory emergency response training for tourist interpreters (Boza González, 2015).
- Trilingual signage marking safe zones, evacuation points, and escape routes.
- Periodic simulation drills involving visitors, artisans, and tour operators.
- Biannual geotechnical slope stability assessments.
- Creation of a municipal contingency fund for tourism emergencies.

Finally, it is essential to recognize that the exclusion of artisans from formalization processes under the pretext of risk perpetuates informality and increases the vulnerability of all stakeholders. As Leoni and Boto García (2023) have demonstrated, tourism destinations that integrate local communities into risk governance are not only more resilient but also more attractive to conscious, cultural, and sustainable tourism markets.

LIMITATIONS

This study presents several limitations that should be acknowledged. First, the geospatial analysis relied on secondary datasets provided by INGEMMET, which, while official and technically validated, may not reflect micro-scale geological variations within the Añashuayco area. Second, due to access restrictions and safety concerns, on-site validation of certain hazard zones—particularly those with high slope instability—was limited, potentially affecting the precision of

exposure mapping. Third, the study adopts a qualitative descriptive design; thus, findings are not generalizable beyond the specific case of the Sillar Quarries and should be interpreted within their contextual scope. Finally, while comparative international experiences were used to enrich the discussion, cultural, institutional, and regulatory differences may limit the direct applicability of such measures in the Peruvian context. Future research could benefit from longitudinal monitoring, integration of local community risk perception surveys, and quantitative modeling of tourism impact scenarios.

CONCLUSIONS

- Community-based tourism in the Sillar Quarries of Añashuayco represents a successful model for valuing geological and cultural heritage, which has contributed to the economic development of more than 500 local stakeholders. However, this potential is constrained by geodynamic hazards that have not been addressed through comprehensive risk management strategies
- Geospatial analysis revealed that the most immediate danger to tourism activity is rockfall associated with intensive quarrying, rather than volcanic or fluvial activity. This risk has a high likelihood of occurrence and a very limited response time, requiring urgent structural interventions such as slope stabilization, installation of wire mesh barriers, and separate pathways for tourists and quarry workers.
- Although the volcanic threat in Añashuayco is of moderate impact, there is a latent risk of ashfall in the event of an eruption of the Misti volcano. This type of hazard can be mitigated through anticipatory territorial planning, visitor education, and public health protocols, as implemented in similar destinations such as Taal (Philippines) and Anak Krakatau (Indonesia).
- Fluvial events, although cyclical and predictable, continue to be neglected in local planning. The implementation of non-structural measures (early warning systems, evacuation signage, and temporary route closures) would allow tourism activities to continue without compromising safety.
- Risk perception has negatively impacted the formalization of artisanal labor, reinforcing informality and limiting access to training programs, municipal licenses, and technical support. This

situation perpetuates artisans' vulnerability and constrains the sustainable development of the destination.

- International experiences demonstrate that tourism in risk-prone areas is not only viable but also more resilient when integrated risk governance strategies are implemented, involving local actors, tourism operators, and technical authorities. Añashuayco could benefit from such practices through the adoption of a comprehensive management plan that combines technical assessment, geotechnical monitoring, continuous training, and participatory design of safety protocols.

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