Geo-hydrological Risk Awareness and Disaster Preparedness in a Mountainous Area of Southern Peru Vulnerable to Disaster

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Abstract. Disaster risk management involves reducing disaster damage to homes, critical infrastructure and the interruption of basic services and developing their resilience. This work analyzes the perception of geohydrological risk by the population living or working in the town of Cuyocuyo (southern Peru), which was affected in previous years by events of landslides, debris flow and floods. In order to analyze the effect of the social perception of geohydrological risk on disaster preparedness in areas under threat from landslides and debris flow, a survey was applied to 65 adult heads of household. The method for estimating results was logit regression. The results show the following: First, the preparation through the acquisition of items necessary to avoid the impact of the disaster is related to indicators of perception of disaster risk and the age of the population. Second, the knowledge and prevention of disaster mitigation significantly depends on indicators of dependency of the place and the affection of the place. Third, the participation of households in trainings and drills to prevent disasters organized by the government depends significantly on the indicators of the perception of probability of the disaster, threat of disaster risk and the identity of the place and Fourth, the modification and reinforcement of the buildings of the settlers depends positively on the dependence of the place.

1. Introduction
The impact of climate change, in events such as floods, landslides, droughts, is determining an increase in natural disasters that occur frequently around the world that affect people's lives and livelihoods [1–3].

Several previous investigations have indicated that the characteristics of risk perception include gender, age [4], education and previous events that have occurred are important factors that affect households in relocation/evacuation readiness [5], [6]. Also, regarding the perception of flood risk and preparedness of Thai citizens according to gender, [7] showed differences in the perception of risk between men and women. In the same way, the behaviors of preparation and response to the risk of floods in Serbia, women were found to be more likely than men to relocate/evacuate [8], although other
studies indicate that gender did not have significant differences in disposition of home evacuation [9]. In relation to age, there are diverse results, regarding the preparation for emergencies and evaluation of the perception of risks, no significant effects of age were found [10], but on the probabilities of relocation and evacuation; younger people are less likely to relocate/evacuate compared to older people [11]. Likewise, it was found that when people are associated with important social networks or groups of friends they have a greater opportunity to know the informal warnings about emergencies and, consequently, to respond in a better way [12], [13]. In general, it is known that people and societies with a high level of formal education are more prepared and respond better to disasters and adaptation to climate change in terms of loss of life, injury, morbidity and damage [14].

The Cuyocuyo Mountains, due to the topography and geological background, experience one of the highest numbers of natural disasters in the region [15], such as landslides, debris flows, floods and other disasters; therefore they represent a great threat to the lives of residents and the security of the property, as well as to the economy of the homes [16]. In the town of Cuyocuyo, in 1984, due to the debris flow event caused in the Jilari ravine, a death occurred [17], and in subsequent years events of similar conditions have occurred, causing great economic losses [16]. However, the mountains cover a large part of its surface and are essential land spaces and contribute to rural revitalization and economic prosperity [18], due to the ancestral agriculture that is practiced.

The objective of this research was to estimate the perception of geohydrological risk and the preparations for the threat of landslides in the mountains of the Cuyocuyo district, Peru, to contribute to the implementation of disaster prevention policies.

2. Study Area

The district of Cuyocuyo (Fig. 1) is located in the north-west of Puno region, at 14° 28'12" S latitude and 69° 32'13" W longitude, 3425 meters above sea level, it is located on the slope from the Amazon river. It covers an area of 503.91 km², of which the majority is dedicated to the agriculture of Andean crops, on the ancestral platforms in the lower and middle parts of the altitude. The predominant soil is composed of clayey gravel, well-graded gravel, clayey sand, and silty sand. According to the Köppen classification, the climate is Cwc, also called cold temperate climate, characterized by wet summers and dry winters. The annual average temperature is 8 ºC, the maximum is 14 ºC and the minimum is 2 ºC [19]. The study area has a risk condition due to its morphological and geological characteristics. Steep slopes, deep and narrow ravines, linked to local geology, and its soil types. The narrow Jilari ravine, as it passes through the town of Cuyocuyo, is affected by an alluvial fan that consists of a debris flow deposit, linked to the activity phases of previous landslides. In particular, urban growth has consisted mainly of various housing and lodging facilities because this area is popular for its natural landscape, platforms, hot springs, among others. The study area was hit by rain events, with greater emphasis in the period 1984, 2003-2007, 2012, 2017 causing many shallow landslides and debris flows, especially in the months of January, February and March of the referred years [15]–[17].
3. Method

3.1. Data source

The identification of adequate data sources to answer the research questions is very important; this article primarily used data from a survey carried out in the town of Cuyocuyo in 2020. The situation of urban households in Cuyocuyo, in relation to the relocation arrangement, their own characteristics, the characteristics of the dwellings, the perception of risk, the sense of place and preparations for the disaster, was the focus of the investigation.

To analyze the risk perception of the population of the town of Cuyocuyo and also to assess their level of preparedness in the presence of a disaster event, 65 people were interviewed through a personalized questionnaire [6], [9], using questions with objective scales (Likert scale, multiple choice, yes/no) or answers open. In general, the list of questions includes sociodemographic (gender, educational level, age, occupation, etc.), degree of knowledge of geohydrological phenomena, intervention in past geohydrological events, perception of exposure to geohydrological risk, information on geohydrological risk, feeling of security and preparations, sense of place, identity of place. The urban area of Cuyocuyo has a total population of around 1,330 inhabitants, who live in a total area of about 14.36 hectares; The questionnaire was made to 65 people, choosing a sample of households near the creek, as well as district authorities. This paper considers the analysis of the importance of knowledge and the effect of other variables such as educational level on the social perception of exposure to geohydrological events, estimating the correlation between the answers to some specific questions strictly linked to these objectives. In this sense, the continuous variables were expressed by the mean and standard deviation, and the categorical variables were shown as percentages and counts. The dependence between two categorical variables of interest was evaluated considering the chi-square test and the two-way contingency table of the person involved (or Fisher's exact test, in case of low expected frequencies). To estimate the robustness and direction of association between two measurable variables
at least on an ordinal scale, Nonparametric correlation coefficients were adopted. In all statistical tests, the level of significance was set at 5%, statistical analyzes were performed using Stata software.

![Figure 2](image)

**Figure 2.** Examples of damage caused by debris flow during the events of 2005-2017. a) Damage to road infrastructure and houses, b) Obstruction of channels and affectation of houses on ravine, c) Flood due to overflow in roads and built homes d) Some remediation works in the upper part of the Jilari ravine.

The buildings located near the bed of the Jilari stream and the Cuyocuyo river were partially buried and damaged. In addition, the extremely high sediment load in the creek (see Fig. 2d). It caused the obstruction of bridges and roads, which resulted in the overflow of materials that flooded the network of adjacent streets. In particular, the debris material invaded the lower floors of houses, urban roads and recreational areas of the locality (see Fig. 2a, b, c). Due to landslides that blocked roads at various points, traffic was interrupted and some homes were left unusable, causing enormous economic losses. Given these events, the authorities adopted some security measures, including the evacuation of more than 250 inhabitants to remote areas of lower risk previously chosen by the residents.

### 3.2 Description of variables

In Table 1, the description of variables is shown to find the results of the investigation.

| Notation of variables | Disaster Preparedness Behavior for the Jilari Stream of the Cuyocuyo District | Si | No |
|-----------------------|--------------------------------------------------------------------------------|----|----|
| y1                    | The household prepared some items necessary to avoid the impact of disaster, such as storing emergency food and water supply, maintaining a working flashlight. | 1  | 0  |
| y2                    | Knowledge learned in housing on disaster prevention and mitigation. | 1  | 0  |
| y3                    | Households participated in drills and drills organized by the government related to disasters with escape drill | 1  | 0  |
| y4                    | The home made some changes to the house, such as the reinforcement of buildings. | 1  | 0  |
| Notation of variables | Measurement of risk perception in the Cuyocuyo study area | Totally agree | In agreement | Neutral | In disagreement | Strongly disagree |
|-----------------------|----------------------------------------------------------|----------------|-------------|---------|----------------|-----------------|
| **Probability**       |                                                          |                |             |         |                 |                 |
| pe1                   | In the next 10 years, there is a great chance that a landslide will occur around your home. | 5              | 4           | 3       | 2               | 1               |
| pe2                   | He has the constant feeling that someday a landslide will happen. | 5              | 4           | 3       | 2               | 1               |
| pe3                   | Compared to other homes, there is a high probability that your home will be attacked by a landslide. | 5              | 4           | 3       | 2               | 1               |
| pe4                   | In recent years there are increasingly certain signs of the occurrence of landslides. | 5              | 4           | 3       | 2               | 1               |
| **Worry**             |                                                          |                |             |         |                 |                 |
| pe5                   | You will feel scared, thinking about landslide.         | 5              | 4           | 3       | 2               | 1               |
| pe6                   | You are concerned about the effect of landslides on your home and in the city/community. | 5              | 4           | 3       | 2               | 1               |
| **Unknown**           |                                                          |                |             |         |                 |                 |
| pe7                   | When a landslide occurs, you must resign yourself to fate. | 5              | 4           | 3       | 2               | 1               |
| pe8                   | Do you think fate prescribes a landslide?                | 5              | 4           | 3       | 2               | 1               |
| pe9                   | You feel like everything is ruined when a landslide occurs at your house. | 5              | 4           | 3       | 2               | 1               |
| **Controllability**   |                                                          |                |             |         |                 |                 |
| pe10                  | Land displacements can be controlled through suitable methods (such as structural projects). | 5              | 4           | 3       | 2               | 1               |
| pe11                  | With a massive prevention and monitoring system, you are not afraid of landslide. | 5              | 4           | 3       | 2               | 1               |
| pe12                  | Despite the uncontrollable occurrence of a disaster, you can still reduce the loss through proper prevention. | 5              | 4           | 3       | 2               | 1               |
| **Threats**           |                                                          |                |             |         |                 |                 |
| pe13                  | In the next 10 years, your home and land will be subject to disasters in the event of a landslide. | 5              | 4           | 3       | 2               | 1               |
| pe14                  | In the next 10 years, your safety and that of your family will be threatened by the occurrence of a landslide. | 5              | 4           | 3       | 2               | 1               |

| Measurement of the sense of place in the Cuyocuyo study area | |
|-------------------------------------------------------------|-----------------|-------------|---------|---------|----------------|-----------------|
| **Identity of the place**                                   |                 |             |         |         |                 |                 |
| se1                                                          | I'm used to the lifestyle here, I don't want to move from here. | 5          | 4         | 3       | 2               | 1               |
| se2                                                          | I'm afraid of disaster, but I don't want to leave here yet, because my roots are here. | 5          | 4         | 3       | 2               | 1               |
| se3                                                          | Impossible that I can separate myself from the town and the townpeople. | 5          | 4         | 3       | 2               | 1               |
| se4                                                          | I never thought that I would move away from the town and live in other places. | 5          | 4         | 3       | 2               | 1               |
| **Place dependency**                                        |                 |             |         |         |                 |                 |
| se5                                                          | I am proud to live in this town. | 5          | 4         | 3       | 2               | 1               |
| se6                                                          | Living in this town makes me feel more satisfied, compared to other places. | 5          | 4         | 3       | 2               | 1               |
| se7                                                          | My love for this town is stronger than anywhere else. | 5          | 4         | 3       | 2               | 1               |
| **Honey to the place**                                      |                 |             |         |         |                 |                 |
| se8                                                          | When I go out, I always think of the town where I live. | 5          | 4         | 3       | 2               | 1               |
| se9                                                          | Unless I'm out on errands, I generally prefer to stay in town. | 5          | 4         | 3       | 2               | 1               |
| se10                                                         | I feel like in this town I can really be myself | 5          | 4         | 3       | 2               | 1               |
| **Eda**                                                      | Age of the interviewee in years |         |             |         |                 |                 |
3.3 Descriptive statistics of the variables
Table 2 shows the descriptive statistics of the main variables surveyed to households in the Cuyocuyo district of Sandia province. As can be seen, 65 household members whose ages range between 18 and 89 years were surveyed, with an average age of 41 years. 56% of the heads of households surveyed are men. The variables from pe1 to pe14 are perception indicators in the study area. While the variables from se1 to se10 are indicators of the sense of place (see Table 1). The variables pe1-pe14 and se1-se10 are measured on a Likert scale from 1 to 5. A rating of 5 in the variables of pe1-pe14 indicates that there is a high degree of perception of the occurrence of the disaster; while in the variables of se1-se10 a value of 5 indicates a high degree of belonging to the place.

Table 2. Descriptive statistics of variables.

| Variable | N  | Promedio | Std. Dev. | Mínimo | Máximo |
|----------|----|----------|-----------|--------|--------|
| y1       | 64 | 0.89     | 0.31      | 0      | 1      |
| y2       | 64 | 0.83     | 0.38      | 0      | 1      |
| y3       | 64 | 0.13     | 0.33      | 0      | 1      |
| y4       | 64 | 0.08     | 0.27      | 0      | 1      |
| y5       | 64 | 0.05     | 0.21      | 0      | 1      |
| pe1      | 64 | 4.19     | 0.53      | 2      | 5      |
| pe2      | 64 | 4.08     | 0.63      | 1      | 5      |
| pe3      | 64 | 4.16     | 0.95      | 1      | 5      |
| pe4      | 64 | 4.19     | 0.96      | 1      | 5      |
| pe5      | 64 | 4.23     | 1.08      | 1      | 5      |
| pe6      | 64 | 4.11     | 0.98      | 1      | 5      |
| pe7      | 64 | 3.42     | 1.28      | 1      | 5      |
| pe9      | 63 | 3.06     | 1.01      | 1      | 5      |
| pe10     | 64 | 2.72     | 1.13      | 1      | 5      |
| pe11     | 64 | 2.67     | 0.93      | 1      | 5      |
| pe12     | 64 | 3.05     | 0.97      | 1      | 5      |
| pe13     | 64 | 3.23     | 1.02      | 2      | 5      |
| pe14     | 64 | 4.61     | 0.49      | 4      | 5      |
| se1      | 64 | 4.16     | 0.72      | 2      | 5      |
| se2      | 64 | 4.28     | 0.55      | 2      | 5      |
| se3      | 63 | 4.14     | 0.74      | 1      | 5      |
| se4      | 63 | 4.22     | 0.91      | 2      | 5      |
| se5      | 64 | 4.73     | 0.45      | 4      | 5      |
| se7      | 62 | 4.39     | 0.52      | 3      | 5      |
| se8      | 61 | 3.82     | 0.85      | 2      | 5      |
| se9      | 58 | 3.09     | 1.03      | 1      | 5      |
| se10     | 58 | 3.38     | 0.91      | 1      | 5      |
| Edu      | 64 | 1.30     | 0.75      | 0      | 3      |
| Ant      | 62 | 0.56     | 0.50      | 0      | 1      |
| Gen      | 59 | 0.56     | 0.50      | 0      | 1      |
| Eda      | 64 | 41.44    | 18.72     | 11     | 89     |
| Fam      | 63 | 4.03     | 2.00      | 1      | 9      |
4. Results and discussions

Table 3 shows the factors that influence the probability of preparation to avoid the impact of the disaster (y1), knowledge and prevention and mitigation of the disaster (y2), participation and training of drills (y3) and, changes and reinforcements of buildings (y4), estimated using a logistic regression model.

| Risk perception indicators          | Independent variables | Model 1 | Model 2 | Model 3 | Model 4 |
|------------------------------------|-----------------------|---------|---------|---------|---------|
| Landslide perception (pe2)         | Effect                | 0.071** | 0.039*  | 0.078*  | 0.049*  |
| Perception of landslide affect the house (pe3) | Probability | 0.017   | 0.094   | 0.056   | 0.054   |
| Evidence of landslide in recent years (pe4) |                      |         |         |         |         |
| Exposure of the house and land to landslide (pe13) |                      |         |         |         |         |

| Indicators of sense of place       |                      |         |         |         |         |
|------------------------------------|-----------------------|---------|---------|---------|---------|
| Identity of the place (se4)        | Effect                | -0.065  | 0.131   |         |         |
| Dependence of the place for the satisfaction received (se6) | Probability |         |         |         |         |
| Dependence of the place for the love of the place (se7) |                      | 0.189** | 0.038   | -0.067* | 0.065   |
| Sweetheart of the place (se8)      |                      | -0.119*** | 0.021   |         | 0.033*  | 0.076   |

| Individual control variable        |                      |         |         |         |         |
|------------------------------------|-----------------------|---------|---------|---------|---------|
| Interviewee's age (Eda)            | Effect                | 0.004*** | 0.01    |         |         |

The results of model 1 show that the constant perception that households have about the landslide one day (pe2), and the perception of probability of the landslide that attacks the house (pe3) and the age of the settlers influence positively in the acquisition of necessary items to avoid the impact of the disaster either through food, water supply and cleaning (y1). This result is consistent with the hypothesis of self-protection and self-management capacities to reduce the vulnerability of natural risks linked to knowledge of the territory and proximity to the environment [20].

In model 2, knowledge and prevention of disaster mitigation (y2) depends significantly on indicators of dependence on the place and the affection of the place. This finding is consistent with the hypothesis that the sense of place is a factor that influences household disaster preparedness [6].

Regarding the dependence of the place, the result shows that the more satisfied the inhabitant is (se6), there is a greater probability for the knowledge and prevention of disaster mitigation; while the indicator of affection for the place measured through "when I go out, I always think of the town where I live" (se8) has a negative effect. The effect of site dependency is a factor influencing disaster prevention and mitigation [6].

Model 3 shows that the participation of households in trainings and drills to prevent disasters organized by the government (y3) is directly related to the risk perception indicators related to the evidence of landslides in recent years (pe4) and exposure of the house and land to landslides (pe13). Likewise, y3 is inversely related to the place identity variable (se4).

In model 4, the modification and reinforcement of the buildings of the inhabitants (y4) is directly related to the affection of the place. In other words, the sense of place positively influences the prevention and mitigation of natural disasters [6], [9].
Citizen participation is important in the prevention of geo-hydrological disasters, and the implementation of mechanisms such as social networks or the use of mobile phones for data collection [21]. The district of Cuyocuyo is located in an area with steep cultivation systems, it will be necessary to take into account adaptation aspects to prevent landslides or avoid the loss of soil, as mentioned [22], being of particular interest remote sensing for the inventory of landslides [23].

5. Conclusions
Using data obtained from surveys of households threatened by landslides, binary logistic regression models were established to relate household risk perception, sense of place, and disaster preparedness.

When households perceive that the disaster can be controlled by appropriate methods, there is a greater likelihood of preparedness to avoid the disaster; while when the perception of the occurrence of the disaster is uncontrollable, the probability of preparing for the occurrence of the disaster decreases.

The capacity for self-protection to reduce the vulnerability of natural risks is linked to knowledge of the territory and proximity to the environment, sense of place, dependence on the place.

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