Risk assessment for earthquakes, debris flow and flooding in the ah 03 de octubre, in chosica, district of lurigancho, Lima

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Abstract- In the district of Lurigancho, in spite of being a district that presents many natural hazards, there are no risk evaluations in all its sectors of high and multiple exposure, which would lead to the impossibility of proposing control measures for such risks in these sectors, which would result in future damages and losses. The present study allows to deepen the knowledge of the risks associated with the AH 03 de Octubre (flood, debris flow and earthquake), so it will allow to generate semi-quantitative data on its vulnerability; and from the risk assessment to support the labor of decision makers at the local or regional government level. The methodology considered was based on the structure of the manual for the evaluation of risks originated by natural phenomena of the National Center for the Estimation, Prevention and Reduction of Disaster Risks (CENEPRED). The risk levels obtained for the hazards present were generally high, with some slight variations in the percentage of blocks, which shows that the AH 03 de Octubre has a highly vulnerable population.

1. Introduction
The entire territory of Peru at different times in its history has suffered various types of calamities such as earthquakes, floods, landslides, avalanches, among others, and in each event with regrettable results of loss of life and property. Society is not prepared because contingency plans only exist at the level of the authorities and do not reach the population. After these adverse events, in the same way, the response is not the most accurate due to lack of good organization at all levels, lack of planning tools or lack of resources to deal with the adverse event.

The town of Chosica in the district of Lurigancho is located at what is known as the entrance to the highlands where two rivers converge, the Rimac River and the Santa Eulalia River; the district also has an average of 15 active streams that are affected during the rainy season (summer) because the slope is steep (O’Connor, 1988). In summer during the rainy season, rainfall has special characteristics in terms of duration, frequency and intensity that finally result in the occurrence of debris flows or low-intensity alluvium, also known as Huaycos.

Within Chosica is located the Asentamiento Humano (AH) 03 de Octubre, adjacent to the Rimac River, and is located at river level and with a predominance of informal constructions, and protected from the river by a wall that could collapse; there is also the mouth of a creek near the settlement, and to this is added the fact that Lima is an area that expects a high intensity earthquake, according to specialists of the IGP.

Based on what has been mentioned in the previous paragraphs, the following has been determined as the study problem: The insufficiency of data in the study area and therefore of planning tools for disaster risk management in the AH 03 de Octubre, to determine its risk level; therefore, the objective of this study is to carry out the risk assessments of disasters originated by seismic movement, debris flow and flooding in this settlement.
2. Theoretical background

2.1 Disaster risk assessment

Risk assessment is a process that helps determine the nature and extent of that risk by analyzing hazards and evaluating existing conditions of vulnerability that could result in damage to exposed people and the assets, services, livelihoods and environment on which they depend. Risk assessment is therefore an integral part of decision-making and policy-making processes, and requires close collaboration between different parts of society (PNUD, 2010, p. 01).

Risk assessment involves having a detailed knowledge of the quantitative and qualitative characteristics of risk, as well as the factors that determine it and its physical, social, economic and environmental consequences. Its importance for disaster risk reduction was explicitly addressed during the International Decade for Natural Disaster Reduction IDNDR 1990-2000 "by the year 2000, all countries, as part of their plans for sustainable development, should have conducted a comprehensive natural hazard risk assessment and incorporated its results into their development plans" (EIRD, 2004, p. 69).

The Risk Assessment is an instrument that is part of the disaster risk estimation process, which is carried out when there is evidence of imminent risk and there is evidence of high risk due to past events. This tool consists of a manual prepared by CENEPRED, which indicates the methodology which consists of calculating the level of hazard, the level of vulnerability, the level of risk, and risk control.

2.2 Danger

Potentially harmful physical event, phenomenon and/or human activity that may cause death or injury, property damage, social and economic disruption or environmental degradation (EIRD, 2004).

According to the CENEPRED manual, the hazard is composed of factors, the triggering factors and the conditioning factors; in addition, the evaluation parameters are taken into account for the calculation of the hazard level. Triggering factors are external factors that cause or trigger instability (González de Vallejo, 2002). The conditioning factors are those that depend on the nature, structure and shape of the terrain itself (González de Vallejo, 2002). Evaluation parameters are the variables or indicators that allow defining the characteristics of the hazard and that are quantifiable or measurable.

2.3 Vulnerability

According to ISDR (2004), vulnerability is a condition determined by physical, social, economic and environmental factors or processes that increase the susceptibility of a community to the impact of hazards. In this sense, exposure to hazards is a necessary condition for losses or damages to exist which can be understood as a determinant of vulnerability, but it does not determine the degree or level of these damages, since they depend on the intrinsic conditions of the exposed elements, i.e., on fragility and resilience; the greater the exposure, the greater the vulnerability. On the other side, fragility refers to the physical conditions of a community or society and is of internal origin; the greater the fragility, the greater the vulnerability (CENEPRED, 2014). Resilience refers to the level of assimilation or recovery capacity of human beings and their livelihoods in the event of a hazard, and is associated with social and organizational conditions of the population; the greater the resilience, the lesser the vulnerability” (CENEPRED, 2014). The condition of the population according to vulnerability factors is shown in Figure 1.

2.4 Risk

Risk is the probability of harmful consequences or expected losses (death, injury, property, means of subsistence, interruption of economic activity or environmental degradation) resulting from interactions between natural or anthropogenic hazards and conditions of vulnerability (ISDR, 2004).

The equation for calculating the risk is as follows:

\[ R = f(P, V) \]

Where:

- \( R \) = Risk
- \( f \) = In Function
P = Danger with intensity greater than or equal to \( i \) during a period of exposure
V = Vulnerability of an exposed element

Risk is, therefore, a latent condition that captures a possibility of losses in the future. This possibility is subject to analysis and measurement in qualitative and quantitative terms.

3. Methodology

The study is carried out in the Asentamiento Humano 03 de Octubre, in the Chosica sector of the Lurigancho district of the province of Lima in the Lima region. It is located between the Pedregal pedestrian bridge and the National University of Education Enrique Guzmán y Valle, and adjacent to the Rimac River.
The Asentamiento Humano (AH) 03 de Octubre is located between the mouth of Santo Domingo Creek, Típuc Amaru Street, 1° de Mayo Street and the Rímac River; that is, on the left bank of the Rímac River, near the mouth of Pedregal Creek on the opposite bank and close to the Universidad Nacional de Educación Enrique Guzmán y Valle - La Cantuta. It is located adjacent to the Rímac River, only 4.5 m from it, part of the settlement is in the marginal strip and part could also be found in the marginal strip of the Santo Domingo Creek, although it is worth mentioning that this has not been delimited by the National Water Authority. The association is at the level of the Rímac River on an alluvial deposit and is protected from the river waters by a retaining wall that has collapsed in the past during heavy rains and maximum floods.

It has a population of 189 people that make up 48 families; the area of the settlement is 5072.7 m², which indicates a density of 373 people/hectare. The population of the area is predominantly immigrants from Lima Provinces or their descendants; 51% of the population is female and 49% male. The AH 03 de Octubre has persons at risk among children, single mothers, the elderly and the physically handicapped. The population demands support for them. The main characteristic of the constructions in the houses is reinforced masonry material, the distribution of rooms is generally larger than three rooms, with more free spaces.

3.1 Design of the study
The present research considered the structure of the manual for the evaluation of risks originated by natural phenomena of the National Center for the Estimation, Prevention and Reduction of Disaster Risks (CENEPRED). This manual indicates the use of the hierarchical analysis process for the validation of the values assigned to the parameters to be processed; it is recommended for evaluating non-quantitative parameters and helps decision makers to choose among many decision alternatives on the basis of multiple criteria. In general terms, the hierarchical analysis process is a method of decomposing complex structures into their components, arranging these components or variables in a hierarchical structure, obtaining numerical values for the preference judgments and finally synthesizing them to determine which variable has the highest priority. To obtain these weights, responses (numerical or verbal) to a series of questions comparing two parameters or two descriptors to a series of questions are required. According to Toskano Hurtado (2005), this is based in Table 1.

Table 1. Saaty Scale

| Intensity | Definition | Explanation |
|-----------|------------|-------------|
| 1         | Of the same importance | 2 activities contribute equally to the objective |
| 3         | Medium Importance | Experience and judgment slightly favor one activity over the other |
| 5         | Strong Importance | Experience and judgment strongly favor one activity over the other |
| 7         | Very strong or demonstrated | One activity is much more favored than the other; its predominance was demonstrated in practice |
| 9         | Extreme | The evidence favoring one activity over the other is absolutely and totally clear |
| 2, 4, 6, 8 | Intermediate values | When a commitment of the parties between adjacent values is required |

Reciprocals: \( a_{ij} = 1/a_{ij} \)  

Source: Saaty 1980

For hazard analysis, the cadastral information of the study area was obtained in dwg format and exported in shp format, in order to determine its implication in the areas of influence of the hazards.
associated with the area and that could affect it, i.e., exposure was determined. Data for the hazards were obtained from the database of the National Geographic Institute, as well as from the Disaster Risk Management Information System, in shp format. Socioeconomic information by block and lot was obtained from the National Institute of Statistics and Informatics (INEI) and SIGRID. This information was stored and processed in a database at the lot level, in a GIS software. The triggering factor, conditioning factors and evaluation parameter were identified, for each hazard associated with the study area (Tables 2, 3 and 4), and evaluated according to the hierarchical analysis process (CENEPRED, 2015). The debris flow hazard scenario is a precipitation of less than 75% and occurs every two years; the river overflow hazard scenario is a precipitation between 75% and 90% and occurs every five years; and the seismic movement hazard scenario is an earthquake of 6 to 7.5 degrees Richter and VII on the Mercali scale; and the seismic movement hazard scenario is an earthquake of 6 to 7.5 degrees Richter and VII on the Mercali scale.

| Table 2. Factors triggering and conditioning debris flow |
|--------------------------------------------------------|
| Triggering Factors | Conditioning Factors                  |
| Rainfall          | Lithology  | Pending | Proximity to the marginal strip |
|                    | Source: Own elaboration                |

| Table 3. Factors triggering and conditioning debris flow |
|--------------------------------------------------------|
| Triggering Factors | Conditioning Factors                  |
| Rainfall          | Lithology  | Pending | Proximity to the marginal strip |
|                    | Source: Own elaboration                |

| Table 4. Factors triggering and conditioning debris flow |
|--------------------------------------------------------|
| Triggering Factors | Conditioning Factors                  |
| Seismic magnitude | Hypocenter | Geomorphological Units | Lithology |
|                    | Source: Own elaboration                |

In the vulnerability analysis, the descriptors and parameters associated with the analysis of each hazard studied, vulnerability was analyzed taking into account the vulnerability factors (exposure, fragility and resilience) and the dimensions of vulnerability (environmental, economic and social), this as double entry tables (see table 5, 6, 7, 8, 9 and 10). Then the descriptors will have a weighted weight based on Saaty’s hierarchical analysis process; this was worked on a spreadsheet and then exported to the GIS program database. The GIS program proceeded to generate base maps of the vulnerability of each lot to each hazard of the study, then a map of the level of vulnerability per lot was generated for each hazard studied (CENEPRED, 2015).

| Table 5. Parameters to be used in the fragility and resilience factors in the social dimension in the face of debris flow. |
|----------------------------------------------------------------------------------------------------------------------|
| In the Social Dimension                                                                                                   |
| Fragility                                                                                                               |
| - Age group                                                                                                             |
| - Disability                                                                                                            |
| Resilience                                                                                                              |
| - Type of health insurance                                                                                              |
| - Educational level                                                                                                      |
| - Beneficiary of social programs.                                                                                       |
| - Attitude towards risk.                                                                                               |
| Source: Own elaboration                                                                                                |
Table 6. Parameters to be used in the fragility and resilience factors in the economic dimension to debris flow.

|                | Fragility                                                                 | Resilience                                                                 |
|----------------|---------------------------------------------------------------------------|---------------------------------------------------------------------------|
| **In the Economic Dimension** | - Number of floors of the building | - Type of housing                                                            |
|                | - Predominant material of the walls                                      | - Tenancy regime of the dwelling                                             |
|                | - Predominant material of the roof                                        | - Type of work occupation                                                   |
|                | - Predominant material of the floor                                       |                                                                          |
|                | - State of conservation of the dwelling                                  |                                                                          |

Source: Own elaboration

Table 7. Parameters to be used in the fragility and resilience factors in the social dimension to debris flow.

|                | Fragility                                                                 | Resilience                                                                 |
|----------------|---------------------------------------------------------------------------|---------------------------------------------------------------------------|
| **In the Social Dimension** | - Age group                                                               | - Type of health insurance                                                  |
|                | - Disability                                                               | - Beneficiary of social programs.                                          |
|                |                                                                          | - Attitude towards risk.                                                   |

Source: Own elaboration

Table 8. Parameters to be used in the fragility and resilience factors in the economic dimension to debris flow.

|                | Fragility                                                                 | Resilience                                                                 |
|----------------|---------------------------------------------------------------------------|---------------------------------------------------------------------------|
| **In the Economic Dimension** | - Number of floors of the building | - Type of housing                                                            |
|                | - Predominant material of the walls                                      | - Tenancy regime of the dwelling                                             |
|                | - Predominant material of the roof                                        | - Type of work occupation                                                   |
|                | - Predominant material of the floor                                       |                                                                          |
|                | - State of conservation of the dwelling                                  |                                                                          |

Source: Own elaboration

Table 9. Parameters to be used in the fragility and resilience factors in the social dimension to seismic movement.

|                | Fragility                                                                 | Resilience                                                                 |
|----------------|---------------------------------------------------------------------------|---------------------------------------------------------------------------|
| **In the Social Dimension** | - Age group                                                               | - Tipo de seguro de Salud                                                   |
|                | - Disability                                                               | - Nivel educativo                                                           |
|                |                                                                          | - Beneficiario de programas sociales.                                      |
|                |                                                                          | - Actitud frente al riesgo.                                                 |

Source: Own elaboration
Table 10. Parameters to be used in the fragility and resilience factors in the economic dimension to seismic movement

| In the Economic Dimension | Fragility                                      | Resilience                                      |
|---------------------------|-----------------------------------------------|-------------------------------------------------|
|                           | Number of floors of the building              | Corresponds to:                                 |
|                           | Predominant material of the walls             | - Type of housing                               |
|                           | Predominant material of the roof              | - Tenancy regime of the dwelling                 |
|                           | Predominant material of the floor             | - Type of work occupation                       |
|                           | State of conservation of the dwelling         |                                                 |

Source: Own elaboration

For determining the risk distribution, in the GIS software, each lot was linked to the majority hazard level in the area by lot, thus having a database or map of exposed elements at the hazard level, which could be overlapped with the vulnerability map by lot. In the GIS database, the weighting for hazard and vulnerability will be worked, thus obtaining a risk level map at the lot level, which must be done for each study hazard. The ranges of the levels of hazard, vulnerability and risk are obtained from the same ranges obtained from the five descriptors of each parameter, so four ranges of hazard, vulnerability and risk levels are obtained (CENEPRED, 2015).

Finally, to determine the risk controls, an analysis of the results will be made in the risk acceptability and tolerability matrices according to what is indicated in the risk assessment manual of the National Center for Estimation, Prevention and Reduction of Disaster Risk CENEPRED, which will be done for each hazard studied. Risk control measures were then proposed for each hazard associated with the study; the measures were classified into structural measures and non-structural measures. These measures should lead to a tolerable or acceptable level of risk for their application or materialization.

4. Results

Risk was calculated through the convolution of hazard and vulnerability through direct weights, while the level of risk was based on the observed levels of hazard and vulnerability. The maps can be found in the annexes. The following table summarizes the risk levels determined in the debris flow disaster risk assessment process:

Table 11. Debris flow risk matrix

| Danger | Weight of danger | Vulnerability | Weight of vulnerability | Risk  |
|--------|-----------------|---------------|-------------------------|-------|
| 0.158  | 0.38            | 0.484         | 0.62                    | 0.360 |
| 0.132  | 0.38            | 0.259         | 0.62                    | 0.210 |
| 0.112  | 0.38            | 0.138         | 0.62                    | 0.128 |
| 0.102  | 0.38            | 0.075         | 0.62                    | 0.085 |
| 0.096  | 0.38            | 0.044         | 0.62                    | 0.064 |

Source: Own elaboration

Table 12. Debris flow risk level

| RANGES | CLASSIFICATION  |
|--------|-----------------|
| 0.191  | ≤ r ≤ 0.320     | Very High     |
| 0.113  | ≤ r < 0.191     | High          |
| 0.072  | ≤ r < 0.113     | Medium        |
| 0.050  | ≤ r < 0.072     | Low           |

Source: Own elaboration
The following chart and table summarize the risk levels determined in the river overflow disaster risk assessment process:

**Table 13. River overflow risk matrix**

| Danger | Weight of danger | Vulnerability | Weight of vulnerability | Risk  |
|--------|------------------|---------------|-------------------------|-------|
| 0.230  | 0.65             | 0.486         | 0.35                    | 0.320 |
| 0.156  | 0.65             | 0.257         | 0.35                    | 0.191 |
| 0.099  | 0.65             | 0.137         | 0.35                    | 0.113 |
| 0.070  | 0.65             | 0.076         | 0.35                    | 0.072 |
| 0.053  | 0.65             | 0.045         | 0.35                    | 0.050 |

Source: Own elaboration

**Table 14. Risk level in case of river overflow**

| RANGES | CLASSIFICATION |
|--------|----------------|
| 0.191  | ≤ \( r \) ≤ 0.320 | Muy alto |
| 0.113  | ≤ \( r \) < 0.191 | Alto |
| 0.072  | ≤ \( r \) < 0.113 | Medio |
| 0.050  | ≤ \( r \) < 0.072 | Bajo |

Source: Own elaboration

The following table summarizes the risk levels determined in the seismic disaster risk assessment process:

**Table 15. River overflow risk matrix**

| Danger | Weight of danger | Vulnerability | Weight of vulnerability | Risk  |
|--------|------------------|---------------|-------------------------|-------|
| 0.209  | 0.55             | 0.472         | 0.45                    | 0.327 |
| 0.173  | 0.55             | 0.264         | 0.45                    | 0.214 |
| 0.153  | 0.55             | 0.143         | 0.45                    | 0.148 |
| 0.142  | 0.55             | 0.076         | 0.45                    | 0.112 |
| 0.137  | 0.55             | 0.045         | 0.45                    | 0.095 |

Source: Own elaboration

**Table 16. Risk level in case of river overflow**

| RANGES | CLASSIFICATION |
|--------|----------------|
| 0.191  | ≤ \( R \) ≤ 0.320 | Muy alto |
| 0.113  | ≤ \( R \) < 0.191 | Alto |
| 0.072  | ≤ \( R \) < 0.113 | Medio |
| 0.050  | ≤ \( R \) < 0.072 | Bajo |

Source: Own elaboration

5. Conclusions

This year 2020, a directorial resolution was issued establishing a delimitation of the marginal strip of the Rimac River on its left bank, which is where the AH 03 de Octubre is located, but there was no risk assessment in this area, much less taking into account the current delimitation of the marginal strip.

The level of danger from debris flow is high in practically all the lots, which is not noticeable in the field, but is visible in satellite images, since the natural course of the stream has been modified with abrupt curves, which, in the event of an extreme event, would be exceeded, returning to its natural
course, where part of the human settlement is located at the mouth of the river. The risk of flooding due to overflowing of the river is very high in practically all the lots because most of the settlement is located within the marginal strip of the Rimac River, separated from it only by a retaining wall that has collapsed in the past. The marginal strip is classified as a very high-risk zone that cannot be mitigated and is therefore declared uninhabitable. The level of seismic hazard is very high in all the lots because they are located on unstable soil in the area, which is on recent alluvial fluvial material and has been modified for non-technical habitation.

The level of vulnerability to debris flow would be due to flood-type silting and some damage in the area. The results are 50% of the lots at a high level and the other 50% at a moderate level of vulnerability risk, due to the characteristics of these dwellings in the face of the hazards mentioned above. The level of vulnerability to flooding would be due to the increased flow of the river, which would resume its course at maximum flood, which is where part of AH 03 de Octubre is located. The results show that 50% of the lots are at a high level and the other 50% at a moderate level of vulnerability risk, due to the characteristics of these dwellings in the face of the hazards mentioned above. The level of vulnerability to earthquakes is between moderate and high in the different lots, due to the characteristics of the properties, which are mostly informal constructions lacking any construction techniques.

The level of risk of debris flow is practically 50% at a high level and the other 50% at a moderate level, because vulnerability in this case is more important than danger. The level of risk of flooding is high in practically all the lots and very high in a few, because in this case the danger of the river overflowing is more relevant than the vulnerability of the properties. Unlike debris flow, this is a constant flow with a higher flow rate, which is why the results differ from the debris flow risk. The level of earthquake risk is high in 80% of the lots, while in 20% it is moderate. This is because vulnerability is slightly more relevant than hazard, as detailed in the matrices developed.

These results would allow adequate decision making regarding public investment projects to be taken into account to prevent and reduce the risk of disasters in the study area. This thesis will allow the authorities to carry out new risk evaluations in the most critical sectors of the left bank of the Rimac River, taking into account that there is already a delimitation of the marginal strip, which will allow taking control measures to reduce damages and losses in the sector of Chosica, which presents several natural hazards.

The limitations found were that the data used from the technical-scientific institutions showed slight inconsistencies, which had to be contrasted with the president of the association, since due to the COVID 19 pandemic it was not possible to carry out an adequate census, however, the president of the association helped to contrast the data obtained from the technical-scientific institutions, since there are few batches that make up the AH October 03.

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ANNEXES

The risk maps obtained as a result are shown below:

**Figure 3**: Debris Flow Risk Map
Source: Own

**Figure 4**: Risk map for river overflows
Source: Own
Figure 5: Risk map for seismic motion  
Source: Own