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Disordered Urbanization: Analysis of a Slope in Recife/PE

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Abstract:

A common problem in large urban centers is the unrestrained occupation of land in places naturally considered as risk areas, due to the urbanization process and irregular occupation of space. Anthropic action, such as removal of original vegetation and irregular deposition of residues, reduces the soil resistence and increases the risk of natural disasters. The objective of this work is to perform the temporal analysis as well as the cause-and-effect diagram of a slope in the city of Recife, Pernambuco. The slope suffered a sliding process in 2019, bringing several economic and environmental damages, in addition to causing the death of a resident. The temporal analysis was performed for the years between 1975 and 2019 through orthophotocards and images obtained with Google Earth. The cause-and-effect diagram allowed the identification of primary and secondary environmental impacts that most affect the area and its interrelations. With the research, it was identified that the vegetation on the site reduced 83.11% over the years, while the urban area increased dramatically, this being one of the main reasons for the occurrence of landslides. In 1975, the area referring to the urban sprawl practically did not exist; however, this percentage reached 75% of the total area in 2019. Regarding the cause-and-effect diagram, it was found that the factors types of occupation and absence of a sewage network are high-risk indicators for the area.

Keywords: Urbanization; Risk Areas; Temporal Analysis; Urban Management; Erodible Soil.

INTRODUCTION

Several changes are taking place in different sectors of society, including changes in production and consumption. The advancement of technology and innovation are elements that have strengthened these transformations, which are associated with economic development (Santos, 2020).

Governments, organizations, and civil society are increasingly concerned about the environmental damage that accelerated urbanization has brought to the environment, especially regarding the high generation of waste and consumption of raw materials (Santos and Marchesini, 2018).

Therefore, developing techniques for recycling reusable materials is essential for urban and environmental development, especially in fragile areas. From this point of view, governments must implement public policies to reduce the high volume of waste generated. In addition to harming the current generation, the latter can compromise future generations.

The occupation of more vulnerable environments, such as hilltops, valley bottoms, and areas susceptible to flooding, has brought different problems to society due to exposure to risk, danger, and disaster situations. Thus, cities are experiencing expressive population density and growth, linked to catastrophes induced or generated by anthropic factors (Oliveira et al., 2015).

Irregular occupation of areas considered at risk has been one factor that allows landslides to occur, causing environmental, economic, and social damage, in addition to compromising the lives of residents. The occupation of inappropriate places can be noticed in several Brazilian urban centers and occurs mainly due to the lack of public policies for popular housing and the proper use of urban space.

According to the Recife City Master Plan, Law No. 17,511 (2008), urban property fulfills its social function when it provides citizens with access to a good quality of life, social justice, accessibility, and the development of economic activities. Recife's Civil Defense Council has direct participation of the population from risky areas and shows the role of establishing policies, plans, and bases for adequate risk planning and management. In addition, the planning foresees the general objectives of urban environmental policy, including sustainable development and environmental quality while preserving natural ecosystems.

According to Scherer and Amaral (2020), cities represent an environment of concentration of people marked by the favorable formation of a place of positive externalities arising from these agglomerations. Cities constitute a space for accessing a greater variety of products that facilitate finding activities compatible with their profiles.

Also, according to the authors, Brazil is a country marked by a certain asymmetry between cities due to expressive regional heterogeneity. Cities represent an element of local articulation and transformation, which depends on their scale, the nature of their productive base, their location, and transport infrastructure.

Recife represents one of the main urban centers in the Brazilian Northeast region, presenting an economy marked by the tertiary sector, including services, commerce, and public administration. The slope analyzed in this work is in the Dois Unidos neighborhood, which belongs to the Administrative Political Region II - RPA 2, with a territorial extension of 3.12 km². In July 2019, it suffered a landslide that resulted in the death of one resident, in addition to causing several social, economic, and environmental damages (Prefeitura Municipal do Recife, 2021).

BIBLIOGRAPHIC REVIEW

Urbanization

In recent decades, the national territory has undergone intense changes in its physical and visual space. The urbanization process represents a significant portion of these changes, with the accentuated displacement of the population to large cities and urban centers, generally in search of job opportunities and better quality of life (Oliveira and Giudice, 2017).

However, since the beginning, Brazilian cities have built a precarious scenario in the occupation of their urban space. The lack of adequate infrastructure and the inability to guarantee access to basic services, such as sanitation, health care, electricity, and education, gave rise to an urban problem in a population in a situation of extreme vulnerability (Oliveira and Giudice, 2017).

According to Mantovani (2016), accelerated urbanization, especially in developed countries, shows how unprepared urban spaces are to absorb population demand in basic infrastructure requirements. In this way, the real estate market ends up appropriating the best sectors of the cities and forgetting the places destined for popular housing.

For Abrantes et al. (2018), the dynamics and patterns of land use and occupation are of fundamental importance because of the intense debates on climate change, sustainable development, and environmental preservation. Population density is a variable that will allow better environmental management. That is because areas with greater populations need stronger government actions to reduce pollution and environmental degradation (Yu, Yang and Li, 2019).

In this context of unguarded cities, deprived of conditions to embrace this large contingent of individuals and absorb all this workforce, among the serious negative consequences, there is the process of settlement in vulnerable areas located in hillside regions (Oliveira and Giudice, 2017; Santos and Paula, 2018).

Slope Instability

The mass movements caused on steep slopes, especially those located in urban environments, have drawn the attention of scientists and researchers, due to the critical and unfavorable situation regarding the health, safety, and well-being of the population occupying these places (Santos, Falcão and Lima, 2020).

Although these are natural phenomena resulting from the dynamics of the earth's surface, which will generally occur in places with rugged topography, such as slopes, environmental disasters have become expressive and frequent events, when related to anthropic action, resulting from disorderly occupation and without planning (Santos, Falcão and Lima, 2020).

Anthropic action in a hillside region is directly associated with erosive processes, siltation and contamination of watercourses, inadequate deposition of residues, soil waterproofing, and irregular constructions. All of these activities affect, directly or indirectly, the increase in the instability of a slope, putting the lives of the population residing in this area at risk (Oliveira and Giudice, 2017).

According to Gerscovich (2016), anthropic action represents one of the inducing causes of mass movements by increasing the mobilized shear stresses, increasing the risk of landslides. Actions such as cutting the ground inappropriately, poor execution of landfills, and irregular waste disposal appear as factors that increase risk.

For Mello (2018), the instability process of soil can occur due to the action of water, which may be due to: infiltration, in which the effective tension of the soil and the apparent cohesion reduces due to its saturation; elevation of the groundwater; weight variations; increased runoff and evaporation. Furthermore, the climate is closely associated with mass movements, increasing the weathering process and reducing soil stability.

There are other aggravating factors mentioned by Carvalhais et al. (2019) related to the instability of slopes, such as cuts that change the angle of repose for the slope, irregular deposition of waste, and unplanned housing construction. Another relevant factor is the lack of sanitary sewage, which generates the discharge of sewage directly into the ground, reducing the resistance of the slope.

In this sense, integrated territorial planning is necessary and requires subsidies for research and projects, which synthesize knowledge about the physical environment with mechanisms that provide geological-geotechnical conditions of habitability (Nogueira et al., 2020).

Public Policies and Demographic Occupation

In Brazil, the contemporary social scenario is understood as a legacy from the colonial period, followed by the slavery and feudal system, characterized by the concentration of large tracts of land in the hands of a limited number of owners. The social changes that occurred with the end of the empire and the establishment of the republic, together with the advances of industrialization and urbanization, only reflected in the emergence of modern forms of social deprivation, new facets of the population's needs, now in the urban sphere (Proni, 2017).

The intense influx of people to cities was not followed by urban and housing public policies capable of meeting the demand for housing (Lima, 2020). According to Fundação João Pinheiro (2016), the housing deficit in urban regions in Brazil already exceeds 5 million, in the case of homes lacking at least one type of infrastructure service.

Nationally, Constitutional Amendment No. 26 of 2000 expressly recognized housing as a right of every Brazilian. This legal support is aimed at the human person, seeking to guarantee their dignity, since it is a fundamental right.

At the municipal level, the Recife City Hall Multi-Year Plan was published in 2017, referring to the period 2018-2021, in which land regularization as well as projects for critical areas, where 53% of the population of Recife live, are foreseen. Among the projects covered by the plan, there is the mapping of critical areas in Recife, involving diagnosis and planning. Those are based on a study that updates housing conditions, sewage, garbage collection, lighting, water supply, drainage, and other public services in these communities.

Furthermore, actions to contain the slopes are also planned, such as the execution of containment works, application of geomantic, slope stabilization, stairs, paving, and drainage in risk areas. However, effective actions to mitigate the security problem related to the housing infrastructure in these areas have not yet been observed.
Based on this reality, it is important to understand that the analysis and design of public policies regarding housing is a basic need and of extreme social interest, as it is an instrument that guarantees access to a fundamental right in order to alleviate social inequalities and promote quality of life (Lima, 2020).

METHODOLOGY

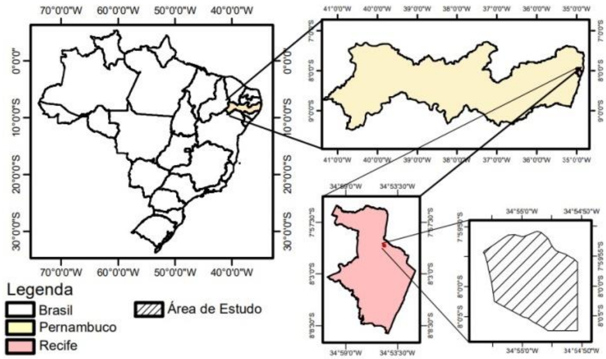
General Characteristics of the Site

The analyzed study area belongs to the city of Recife, Pernambuco, in the Dois Unidos neighborhood, at coordinates 7º 59' 52" S and 34º 54' 57" W, on the street Córrego do Curió, part of the Administrative Political Region II – RPA 2, as shown in Figure 1.

The city of Recife is the capital of the state of Pernambuco and has a territorial area of 218,846 km² with an estimated population of 1,645,727 for the year 2019 (Instituto Brasileiro de Geografia e Estatística - IBGE, 2017). Recife is known as one of the main urban centers in the Northeast region, with an economy dominated by the tertiary sector. In addition, the city concentrates a good part of the civil construction sector and the transformation industry and is responsible for most of the exports of knowledge and technologies for enterprises (Prefeitura Municipal do Recife, 2021).

The Municipal Human Development Index (IDHM) of the city of Recife was 0.772 for the year 2010. Between 2000 and 2010, education, longevity, and income were the services that grew the most (Prefeitura Municipal do Recife, 2021).

Figure 01: Area location



Source: Prepared by authors with the help of Qgis software.

The municipality has a humid tropical climate with an annual average of 25.4 ºC, with a rain regime defined in two different periods: rain in the autumn-winter season and drought in September to February (Barros and Lombardo, 2013). In this way, the climate can be understood as tropical rainy in dry summer, in which rainfall affects erosive processes by enabling the carrying of materials (Portela, 2019).

The vegetation is formed by the Atlantic Forest, Floodplain fields, Sandbank, and Mangrove, which are devastated because of landfills and illegal logging. Mangrove vegetation represents an ecosystem of great environmental and economic importance, being one of the most productive regions for carrying the organic matter to estuarine regions and serving as a source of income for a large part of the local population (Barbosa, 2010).

Regarding hydrography, the city of Recife is marked by the Capibaribe River Basin and the small coastal rivers basin 2 - GL2, limited to the north by the Capibaribe River, and the south, by the Ipojuca River basin. The Capibaribe River basin has an area of 7,454.88 km², covering 42 municipalities in the state of Pernambuco (Agência Pernambucana de Águas e Clima - APAC, 2021).

The analyzed slope suffered a landslide process in July 2019, which resulted in the death of one of the residents, in addition to causing several economic and environmental damages (Aprígio, 2019). The main reason pointed out as the cause of the rupture of the slope is the disorderly occupation linked to the heavy rains that occurred in the winter period.

With the site visit, it was possible to notice several factors that increase the risk of accidents, which, in large part, are linked to anthropic factors, such as removal of the original vegetation, absence of an adequate sewage system, and irregular waste disposal. In addition to these factors, there are irregular cuts in the land for building houses and disease-transmitting vectors, increasing the risk to the population's health.

Temporal Analysis

The temporal analysis showed the characteristics of the dynamics of occupation of the site over the years, enabling a more accurate study of the influence of human occupation on the soil stabilization process. In this way, it is possible to assess the evolution of land use and occupation at the site, considering an increase in environmental degradation.

The temporal analysis was performed through the preparation of maps with the areas corresponding to four types of coverage found at the site, namely:

- Vegetation: corresponds to places with treetops, lawns, or plants;
- Exposed soil: corresponds to areas without vegetation or construction;
- Urban stain: corresponds to places that have dwellings or cemented surfaces that increase surface runoff by reducing the infiltration capacity at the site;
- Road system: represents the local roads.

The orthophotocharts were collected at the Pernambuco State Planning and Research Agency (CONDEPE/FIDEM), on a scale of 1:10,000, presenting contour lines equidistant at 5 meters. The orthophotocharts collected from FIDEM represent the location for the years 1975 and 1985. With the help of Google Earth, images were obtained for the region of study from 2009 to 2019.

After collecting the images, their vectorization was carried out using the free software Qgis, which represents a multiplatform of the Geographic Information System (GIS). The software also allows to visualize, edit, and analyze data, giving rise to several layers through different projections (Silva, 2020).

The software enabled the quantitative analysis of the area under study, providing the values corresponding to the area of each type of coverage over time. It also allowed a more in-depth analysis of irregular urbanization, providing characteristics related to the spatial dynamics inserted along the years.

Cause and Effect Diagram

The construction of interaction networks for the area under study allows the identification of direct and indirect environmental impacts and their interrelationships. The interaction network method has as its main advantage a greater understanding of the secondary impacts that affect the site and allows the introduction of statistical parameters that enable the estimation of possible future changes.

The Ishikawa diagram, or cause and effect diagram, was built from information found in the theoretical foundation of the study and in the slope area itself, representing the chains of impacts linked to their possible causes.

The environmental indicators analyzed were reduction of vegetation cover, absence of a sanitary network, types of occupation, and population density. Each indicator was adapted for the area in question. For a better analysis of the factors that increase the risk of slope slides, some site visits were carried out to fully visualize the erosive processes that compromise the stability of the slope.

After building the interactions, the degree of risk for each indicator was obtained, concerning favoring the slope slide process. The classification of the degree of risk was performed using the parameters reported by Santos (2012), in which:

- Low grade – There is no noticeable risk of localized geotechnical or hydraulic accidents, not requiring specific interventions for geotechnical stabilization;
- Medium degree – There is a risk of small and medium-sized geotechnical or hydraulic accidents;
- High degree – There is a risk of serious geotechnical or hydraulic accidents.

RESULTS AND DISCUSSIONS

Remote Sensing Data

Table 1 presents the relative description of the spatial distribution and the quantitative results of the temporal analysis for the slope in 1975, 1985, 2009, and 2019. Table 2 represents the variation rates of each coverage over the years. The types analyzed were exposed soil, vegetation, urban area, and road system.

Table 1: Land use and occupation data

Types of coverage	Area (m²)				Area under study (%)			
	1975	**1985**	**2009**	**2019**	**1975**	**1985**	**2009**	**2019**
Exposed Soil	10000	10400	0	7400	5,55	5,78	0	4,11
Urban Stain	0	0	116300	135000	0	0	64,61	75,00
Vegetation	163400	166500	54600	27600	90,78	92,50	30,34	15,33
Road System	6600	3100	9100	10000	3,67	1,72	5,05	5,56
Total	180000	180000	180000	180000	100	100	100	100

Source: The authors.

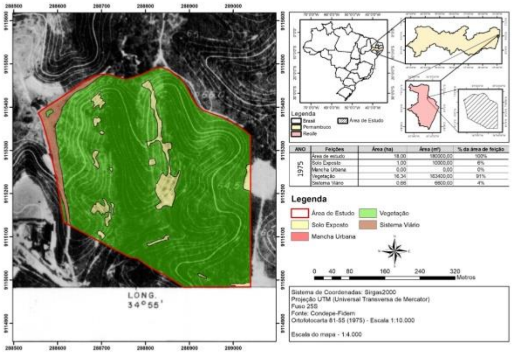
Table 2: Variation rates for 1975, 1985, 2009, and 2019.

Types of coverage	Variation rates (%)			
	1975-1985	**1985-2009**	**2009-2019**	**1975-2019**
Exposed Soil	(+) 4,00	-	-	(-) 26,00
Urban Stain	-	-	(+) 16,08%	-
Vegetation	(+) 1,90	(-) 67,21	(-) 49,45	(-) 83,11
Road System	(-) 53,03	(+) 193,55	(+) 9,89	(+) 51,52

Source: The authors.

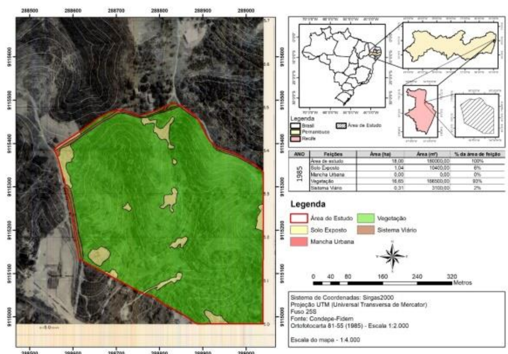
It was necessary to deliver the orthophotocharts for the years analyzed using the Geocentric Reference System for the Americas 2000 (SIRGAS 2000). It is possible to notice the high growth of the urban area and a relevant reduction in the percentage occupied by vegetation over the years. Disorderly occupation coupled with the removal of vegetation for housing construction are factors that increase the risk of landslides. Next, the results in maps obtained with remote sensing are presented in Figures 2, 3, 4, and 5.

Figure 2: Use and occupation of the slope area in 1975.



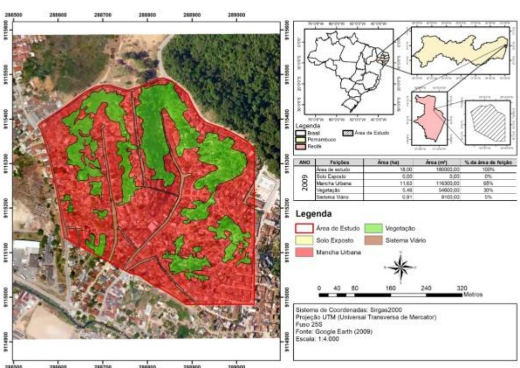
Source: The authors.

Figure 3: Use and occupation of the slope in 1985.



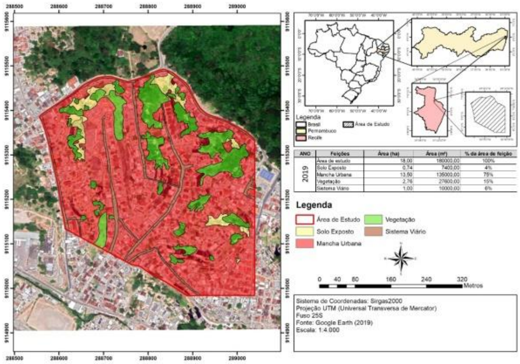
Source: The authors.

Figure 4: Use and occupation of the slope in 2009.



Source: The authors.

Figure 5: Use and occupation of the slope in 2019.



Source: The authors.

Temporal Analyses of Land and Occupation

The area corresponding to the urban sprawl represents one of the typologies that has undergone the most change over these 45 years. In 1975, the area referring to the urban sprawl practically did not exist; however, this percentage reached 75% of the total area in 2019.

This modification is related to the spatial dynamics inserted in the place over the years, promoting the reduction of vegetation and the creation of new constructions that increase the impermeable areas of the region. Between 2009 and 2019, an increase in urban sprawl and the road system is noticeable. This factor can be explained by the need to create new access routes for the movement of people and goods as urbanization grows.

Between 1975 and 2019, the area corresponding to the exposed soil suffered a 26% reduction. The area corresponding to the urban sprawl presented an increase over the years, reaching the mark of 135,000 m² in 2019. Between 2009 and 2019, the percentage of increase referring to the typology of urban sprawl was 16.08%.

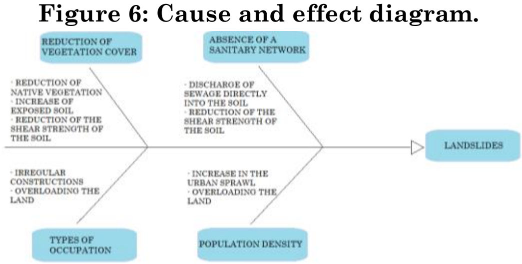
The most alarming change occurred in the vegetation typology, mainly between 1985 and 2009, when the reduction reached the mark of 67.21%, generating concern for the formation of new risk areas susceptible to landslides. The road system showed an increase of 51.52% between 1975 and 2019, increasing the impermeable areas and its consequent runoff.

For Santos (2020), the disorganized use and occupation of land, due to the population increase, may be the result of precarious urban planning and public management, failing to absorb the population increase over the years. Thus, the provision of basic infrastructure for the new agglomerates has become something impossible, increasing the emergence of new irregular settlements that contribute to environmental degradation and the reduction of biodiversity.

Cause and Effect Diagram or Ishikawa diagram

The preparation of the cause-and-effect diagram allowed evaluating the relationship between the sources that generate impacts and their respective environmental indicators, as shown in Figure 6. At the study site, the slope slide was the final/environmental impact analyzed, presenting several causes that can enhance its occurrence.

Figure 6: Cause and effect diagram.



Source: The authors.

For each environmental indicator, some possible causes were identified. The environmental indicator "vegetable suppression" presented, as the main causes of the reduction of native vegetation, the increase of exposed soil and the reduction of the shear strength of the soil. For the "absence of sanitary network" indicator, the causes were the discharge of sewage directly into the soil and the reduction in the shear strength of the soil.

For the environmental indicator "types of occupation", the most relevant causes were irregular constructions and overloading the land. Finally, for the indicator "population density", the most important cause is the increase in the urban sprawl in the place.

The suppression of vegetation cover increases the unprotected area of the soil, reducing its resistance and increasing the potential for landslides. On the analyzed slope, the reduction of vegetation cover presented a medium degree of risk since the vegetation is still partially present at the point of the disaster.

The absence of a health network increases the volume of sewage that is released directly to the ground, resulting in a reduction in its shear strength. It was observed that most of the houses discharge sewage directly to the ground, without any kind of care, making the environmental indicator "absence of sanitation network" an indicator of a high degree of risk (Figure 7).

Thus, it is possible to see that in many parts of the city of Recife, especially on hills and slopes, the minimum requirements reported in the master plan related to basic sanitation are not met, requiring stronger government intervention in these places, in addition to campaigns for social and environmental education to reduce the impacts caused to the natural environment by human action.

Figure 7: Discharge of sewage directly into the ground.

Source: The authors.

At the site, there are constructions along the slope in places considered to be high risk, in which it is possible to analyze the absence of urban planning (Figure 8). These constructions on the slope increase the overload on the land and the mobilizing tensions, making the "type of occupation" indicator an indicator of high risk.

Figure 8: Buildings along the slope.

Source: The authors.

The population density was represented by the increase in the area corresponding to the urban sprawl over time. At the point on the slope where the landslide occurred, it was found that the presence of buildings becomes less dense than at other points around the slope. Thus, population density is considered an indicator of medium risk for the area under study.

CONCLUSION

Accelerated urbanization in the current century can be characterized by high demographic density and socio-environmental factors, such as income inequality and the supply of goods and services. Many regions, such as hilltops, are irregularly occupied, bringing various risks that can affect the lives of residents and society.

Large urban areas have been undergoing the process of formation of unequal and conflicting spaces that enhance socio-environmental conflicts in the relationship between vegetation and urban areas, leading to socio-environmental segregation. The anthropic action presents itself as one of the main inducing causes for the occurrence of landslides, as it increases the mobilized shear stresses of the soil.

With the temporal analysis, it is possible to see the influence that urbanization caused in this region, bringing the formation of risk zones. Between 1975 and 2019 there was a reduction of 83.11% in the vegetation typology, revealing the strong influence of population occupation in the hillside area and its consequent suppression of vegetation cover. This factor enhances the risk of landslides, as the vegetation presents itself as a protection for the area, increasing the resistance to slope rupture.

The most abrupt change was observed between 1985 and 2009 when the reduction of vegetation reached the mark of 67.21%. The area referring to the urban sprawl has increased considerably over time, reaching, in 2019, 75% of the total area under study. The typology referring to the road system showed an increase of 51.52% between 1975 and 2019 due to the need to create new access routes for the movement of people and goods as urbanization grows.

Regarding the cause-and-effect diagram, it was found that the factors suppression of vegetation cover and population density are medium-risk indicators for the area, while the factors types of occupation and absence of a sewage network are high-risk indicators for the area.

Thus, population density can be understood as a control variable that allows for better environmental management, increasing the need for stronger government actions, especially in areas with a larger number of residents, aiming to reduce environmental degradation and training areas considered to be at risk.

It is recommended that in future works carried out for the site, soil reinforcement techniques are analyzed to improve the geotechnical characteristics of the terrain, in addition to the development of educational projects to guide the local population on their role in reducing of natural accidents and environmental preservation.

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