

## APPLICATION OF THE HAZARD MAPPING METHODOLOGY FROM THE GEOLOGICAL SURVEY OF BRAZIL FOR GEOTOURISM ATTRACTIONS

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In January 2022, ten people died when a boulder fell on a tourist boat on Lake Furnas, in the municipality of Capitólio-MG. As a result, since the tragedy, the Geological Survey of Brazil has been conducting geological-geotechnical assessments in areas where ecotourism activities are carried out, with the aim of helping to improve environmental management practices and safety conditions for tourists and other professionals who visit these regions. One of these areas is the José Lutzenberger State Park, located in the municipality of Torres, in the state of Rio Grande do Sul, Brazil. Geologically speaking, it is a group ofinselbergs formed by basalt outcrops in the middle of an extensive coastal plain, creating a relief of cliffs that is much sought after by tourists and fishermen. Geologic hazard mapping was performed by collecting structural, lithological and geomorphologic data and geodynamic features of terrain instability in the face of gravitational mass movements. An unmanned aerial vehicle (drone) was also used to generate a digital elevation model as input for modeling. The analyses presented in this paper were carried out using the hazard methodology of the Brazilian Geological Survey, adapted from the manual developed by the GIDES-JICA project, which consists of dividing the analyzed slope into critical and dispersion areas and then assigning a degree of risk according to the variety and intensity of the observed evidence. The work allowed the identification of the safe areas in the park and the delimitation of areas subject to geological accidents, classified according to the degree of hazard of translational landslides and rockfalls.

*Keywords: Geotechnical Assessment of Geotourism Attractions, Geohazard Mapping Methodology, José Lutzenberger State Park.*

### 1. Introduction

This article is based on the Geotechnical Assessment of a Geotourist Attraction in Torres, RS (Pedrazzi, 2023), carried out by the GSB - Geological Survey of Brazil. The main objective of this assessment was to evaluate the geological hazards to which visitors are exposed in the José Lutzenberger State Park, also known in the region as Guarita Park.

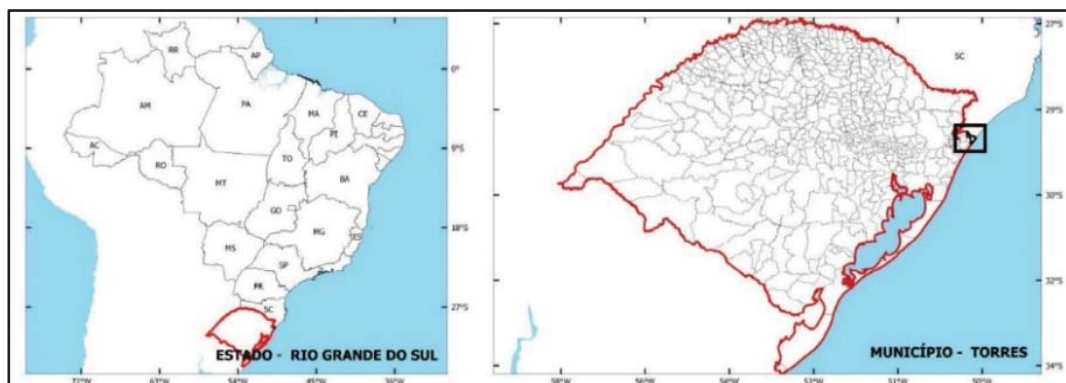


Fig. 1. Location map of the municipality of Torres, situated in the extreme north of the coast (black square) of Rio Grande do Sul State, Brazil.

### 2. Background

The development of ecotourism activities in an unorganized way can increase the degradation of the natural heritage and, above all, the exposure of tourists to natural hazards. This scenario can lead to accidents caused by geological phenomena.

Guarita Park is a geological site, with special interest for the study of geology, a scenario of international geological importance. For this reason, the municipality of Torres is part of the *Caminhos dos Cânions do Sul Geopark*, a region that includes six other municipalities in Rio Grande do Sul and Santa Catarina, as a UNESCO World Geopark.

### 3. Objectives

The objective of this article is to concisely present the Hazard Mapping Methodology from the Geological Survey of Brazil and its potential use for the characterization of tourist attractions susceptible to gravitational mass movements.



Fig. 2. Image of Torre Sul (back left) and Torre da Guarita (front right), located at José Lutzenberger State Park. Credit: Author.

### 4. GSBHMM – Geological Survey of Brazil’s Hazard Mapping Methodology

The GSBHMM used in this study is the result of the adaptation of the Manual for Mapping Hazards and Risks to Gravitational Mass Movements (Pimentel et al. 2018). This manual was developed by the GIDES - Strengthen the National Strategy for Integrated Natural Disaster Management Project, as the result of an agreement signed between the governments of Brazil and Japan through the Japan International Cooperation Agency (JICA) and the Brazilian Cooperation Agency.

According to Pimentel et al. (2018), the hazard assessment consists in dividing the analyzed slope into critical and dispersion areas (Figure 3).

Office Hazard Analysis	<b>Critical Area (CA)</b>	Area most likely to trigger gravitational mass movements (MLIT, 1988, Ministry of Construction, 1996, Ministry of Construction, 2009) and to be hit by mobilized material (MLIT, op.cit., Ministry of Construction, op. cit.). The potential energy of the movement is considered to be concentrated in the affected area (Ministry of Construction, op. cit., Hayashi et. al., 2000).
	<b>Dispersion Area (DA)</b>	Area subject to deposition of the material mobilized during a gravitational mass movement (MLIT, 1988, Ministry of Construction, 1996, Ministry of Construction, 2009). The potential energy of the movement is considered to occur in a dispersed manner in the affected area (Ministry of Construction, op. cit., Hayashi et. al., 2000).

Fig. 3. Characterization of critical and dispersion areas. Source: modified from Pimentel et al, 2018.

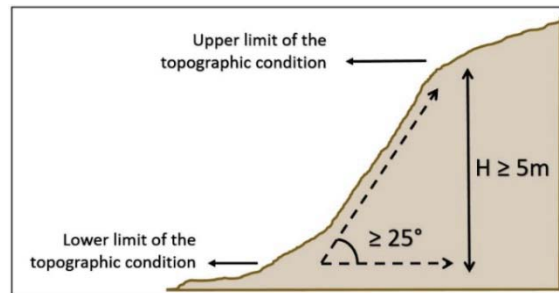
The Hazard Classification Analysis is performed only on the Critical Area (CA). Since these are outbreak areas, it is assumed that the instability conditions are present for mass movement processes to begin, and for this reason, it is assumed that the critical areas, are where the impact force contained in the mass of displaced material is sufficient to destroy buildings, and therefore, are assigned a minimum degree of geological hazard.

The Dispersion Area (DA) is rated one degree lower than the Critical Area because this area may not show evidence of instability resulting from the onset of a gravitational mass movement process, and furthermore, the impact force contained in the displaced material when hitting standard dwellings is not sufficient to destroy them, but only to damage them, at most.

Once the critical and dispersion areas have been delineated, the hazard degree is classified as low, medium, high, or very high.

The potential for translational landslides is identified in the topography by observing the slope inclination and height. The parameters obtained through the analysis of Japanese data and experiments in Brazilian municipalities indicate that the parts of the slope that meet the criteria of slope equal to or greater than  $25^\circ$  and height equal to or greater than 5 m fall between the limits of the topographic condition (Figure 4).

As for the processes of block fall, the methodology divided it into three groups. These groups are defined according to the slope of the rock mass and the presence or absence of a ramp at the base of the slope, since the



presence of a ramp significantly affects the range and trajectory of the rock block (Figure 5).

Fig. 4. Topographic criteria for the translational landslides process. Source: modified from Pimentel et al, 2018.

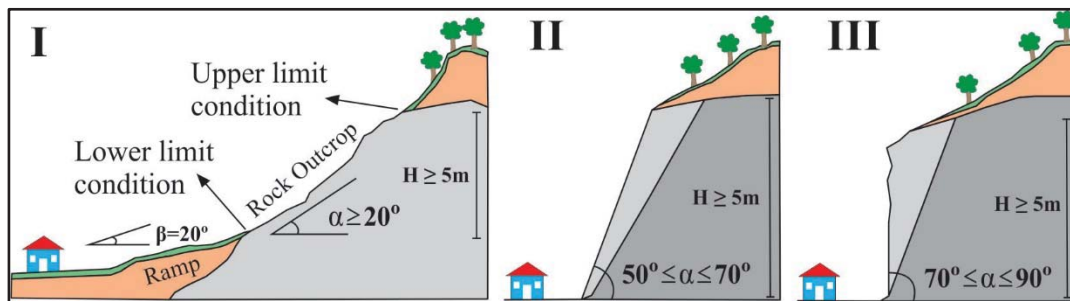


Fig. 5. Group I - rock masses with a ramp; Group II – rock masses without a ramp and slopes with a gradient between 50° and 70°; Group III – rock masses without a ramp and slopes with a gradient greater than 70°. Source: modified from Pimentel et al, 2018.

As for the extension of the lower limit of the dispersion area, the distances are set according to the type of process (Table 1).

Table 1. Summary of Critical Area (CA) and Dispersion Area (DA) delineation rules. Source: modified from Pimentel et al, 2018.

Type of gravitational mass movement	Qualification of the hazardous area	Upper limit	Lower limit	Side limits
Translational landslide	Critical Area	Top + 10m	Base + 1H (30m max.)	End of topographic condition
	Dispersion Area	End CA	Base + 2H (50m max.)	End of topographic condition
Rockfall – Group I Ramp + 20°-50°	Critical Area	Outcrop top	Ramp end = 20°	20° to each side
	Dispersion Area	End CA	2H (200m max.)	20° to each side
Rockfall – Group II Slope = 50°-70°	Critical Area	Outcrop top	½H (100m max.)	End of topographic condition
	Dispersion Area	End CA	1H (200m max.)	End of topographic condition
Rockfall – Group III Slope = 70°-90°	Critical Area	Outcrop top	S H (50m max.)	End of topographic condition
	Dispersion Area	End CA	2H (100m max.)	End of topographic condition

The hazard classification is based on the experience of the researcher in assigning hazard classes to the delineated areas, based on the observation of signs of instability in the terrain and based on the topography. The hazard classification analysis is only carried out on the critical area (CA). As these are outbreak areas, it is assumed that the conditions of instability for the onset of mass movement processes are present there. The dispersion area (DA) is classified at a lower level than the critical area, since this area may not show evidence of instability caused by the triggering of the gravitational mass movement process and also because the magnitude of the damage caused is lower.

## 5. Results

After carrying out the studies, it was possible to conclude that the buildings used in the park are located in safe places, out of reach of gravitational mass movements, as well as a wide area of sandy strip, which can be recommended for use by tourists.

However, two large areas were identified (Figure 6), where there is a risk of people being affected by gravitational mass movements. The area with the highest risk are the rock faces of the *Torre da Guarita*, which was classified as very high hazard for blockfall.

High hazard areas were also identified around the *Torre Sul* and *Torre do Meio*. The *Torre do Meio*, being larger than the others, was divided into five sectors for better description: *Bico do Luiz*, *Furna do Diamante*, *Saltinho*, *Portão* and *Trilha Verde*.

Regarding these five sectors, it was possible to verify that all the points frequented by fishermen and other visitors in the four eastern sectors with cliffs have high hazard for blockfall, while the *Trilha Verde* sector is at high hazard of translational landslides.

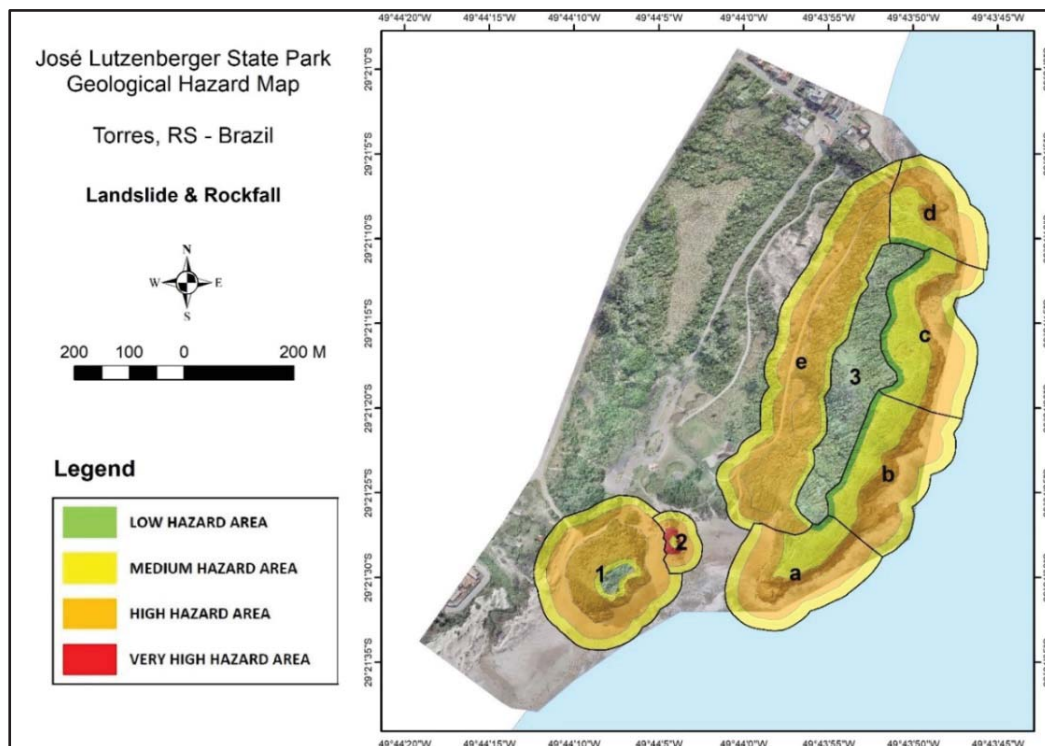


Fig. 6. Geological hazard map for gravitational mass movements delimited and classified according to the GSBHMM. Legend for the map: *Torre Sul* (1), *Torre da Guarita* (2) and *Torre do Meio* (3), split into *Bico do Luiz* (a), *Furna do Diamante* (b), *Saltinho* (c), *Portão* (d) and *Trilha Verde* (e). Source: adapted from Pedrazzi, 2023.

## 6. Conclusions

The GSBHMM has proven to be a viable and reliable option that can be applied to sites with similar relief and geology. In addition, due to being a quantitative method based on physical parameters and consolidated by a large statistical database, is free from external human interference. This quality is of paramount importance in places where environmental and commercial interests are in conflict.

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