1. INTRODUCTION

The purpose of this article is to describe the development of a new hazard mapping and risk assessment methodology in Brazil. This is one of GIDES project outputs that were adapted from Japanese mapping methodologies to the Brazilian reality [Giustina, 2019].

In response to recent major disasters the Brazilian government has worked to reinforce the disaster prevention systems. In the implementation of Brazilian enhancement program in knowledge, skills and experience three main sectors were recognized: 1) urban planning and management; 2) civil defense and 3) disaster prevention science and technology.

2. A BRIEF HISTORY OF OCCUPATION AND EVENTS IN BRAZIL

The Brazilian population has grown strongly since the 1950 decade. In the 1960's the replacement of rural workers by machinery forced them to leave the countryside to the towns. The rural exodus which occurred between 1960-1980 further contributed with the large urbanization across the country. The uncontrolled expansion of towns peripheries generated land degradation with many irregular buildings, resulting in the growth of slums in several metropolises. The government had no control about these buildings. Cities increased disorderly and people started to live in areas with risk to gravity mass movements (GMM) and floods.

There are records of sediment disaster in Brazil since the 17th century. In the state of Rio de Janeiro events of heavy rainfalls occurred in 1966 and 1967 causing more than 1700 deaths due to landslides and floods [Jones, 1973].

In November 2008 at Itajaí Valley (Santa Catarina State) a sediment disaster event affected around 60 towns and more than 1.5 million people.

But the greatest sediment disaster ever recorded in Brazil happened in 2011. It devastated the towns of
Nova Friburgo, Petrópolis and Teresópolis located in the mountain region of the Rio de Janeiro State. This sediment disaster left around 1,000 deceased, 400 missing and over 20,000 without their homes.

3. JAPANESE SEDIMENT-RELATED DISASTER ASSESSMENT

Following multiple large-scale sediment disasters which occurred during the decades of 1960 and 1970 in Japan, laws were put forward defining study guidelines for sediment disaster.

Later, the Sediment Disaster Prevention Act, hereinafter called Japanese Prevention Act, was endorsed in May 2000 in response to a debris flow disaster in June 1999 at Hiroshima Prefecture [Uchida et al., 2009].

The law defines non-structural measures to protect people from sediment-related disasters, including public information regarding hazardous areas, development of early warning and evacuation systems, restriction on new land development for housing or other purposes, and promotion of relocation of existing houses.

Based on this law surveys for identifying hazard areas for all the specific types of sediment disasters, called Basic Survey, are now being performed nationwide.

Using the results of this Basic Survey, vulnerable areas to sediment-related disaster have been classified based on specific parameters (Table 1) of hazard assessment.

The Japanese method comprises specific criteria for 3 types of gravity mass movements (GMM): slope failure, landslide and debris flow. This sediment disaster hazard assessment method using standard parameters are applied to all the slopes and valleys in Japan even if they are different in geology and vegetative cover. The sediment disaster hazard maps are elaborated in a 1:2,500 scale.

In those maps two kinds of hazard areas are shown: “Sediment-related disaster hazard area” (referred to as the ‘yellow zone’) and “Special sediment-related disaster hazard area” (referred as the ‘red zone’). The ‘yellow zone’ and the ‘red zone’ are defined based on topographic conditions and the calculated value of sediment mass force (using equation from Sabo Frontier Foundation, 2016). The red zone is defined where the range of calculated sediment mass force exceeds the buildings strength in the area: destruction is expected. The yellow zone is defined where the range of calculated sediment mass force do not exceed the buildings strength but constructions could suffer some damage [Uchida et al., 2009].

Up until June 30, 2017, 74% of a total 492,722 possible sediment disaster hazard areas had been surveyed in Japan. [http://www.mlit.go.jp/river/sabo/sinpoupdf/graph-170630.pdf].

4. BRAZILIAN SEDIMENT-RELATED DISASTERS ASSESSMENTS

In this section the characteristics of the Japanese and Brazilian surveying methods are discussed as well as the required adaptation of the Japanese procedures to Brazilian reality.

The development of risk assessment studies associated with geodynamic processes in Brazil began in the late 1980’s [Prandini et al., 1987], and in the 90’s the theme was highlighted in scientific meetings (symposia, congresses, conferences) [Tominaga, 2007]. The first attempt to systematize a mapping methodology adapted to the Brazilian conditions was related to the development of Municipal Risk Reduction Plans [Plano Municipal de Redução de Riscos-PMRR de Florianópolis, 2007]. Nowadays there are several municipal, state and federal Brazilian agencies dealing with sediment-

<table>
<thead>
<tr>
<th>Type of sediment disaster</th>
<th>Standards</th>
</tr>
</thead>
<tbody>
<tr>
<td>Slope failure</td>
<td>a) Slope of 30° or steeper and 5 meters or higher; b) 10 meters or less in horizontal distance from the top of the slope; c) Less than twice the height of the sloped region from the bottom of the slope (or 50 meters if over 50 meters high).</td>
</tr>
<tr>
<td>Landslide</td>
<td>a) Landslide zone (zone where there are landslides or the risk of landslide); b) Within a distance from the bottom of the landslide zone equivalent to the length of landslide mass (or 250 meters if over 250 meters).</td>
</tr>
<tr>
<td>Debris flow</td>
<td>a) Gradient of 2° or steeper downstream of the alluvial fan head in a mountain stream with risk of debris flow.</td>
</tr>
</tbody>
</table>

Table 1] Japanese criteria for sediment-related disaster hazard assessment [e.g. Sabo Frontier Foundation, 2016].

Due to sediment-related disasters at Santa Catarina, Alagoas, Pernambuco and Rio de Janeiro states, the Brazilian government approved the Protection and Civil Defense National Policy [Law N° 12608, 2012]. In order to achieve the requirements demanded by this law, the federal government requested CPRM to assess risk and susceptibility for landslides and floods in 821 priority municipalities of Brazil. CPRM has been surveying risk assessment since 2011 and susceptibility analysis since 2013. Up to end of 2018 almost 1500-risk assessment, 400-susceptibility charts and 8-geotechnical charts were produced.

4.1 The CPRM Surveys

The Territorial Management Department (DEGET) develops geoscientific information regarding physical environment for public and private managers in order to assist land use management and to support sustainable development.

Table 2 shows characteristics of different surveys carried out by CPRM and Japanese and GIDES surveys methods which will be further explained in the next section. It is noteworthy that each survey has different purposes and specific scales.

Risk analysis considers the possibility of human lives and properties losses in urbanized areas which are potentially or historically affected by natural disasters mainly related to mass movements and floods.

Data of large scale are used for Risk Management in prevention and response actions like forecast, early-warning systems, contingency plans and structural countermeasures (Figs.1 and 2).

Susceptibility represents a natural possibility of sediment related disaster or floods to occur classifying the terrain in 3 categories (Table 2). Surveys are represented in semi-detail-scale charts, commonly used for territorial management, like expansions of urban areas (Fig.2).

Geotechnical chart (Table 2) is a preventive tool that aims to guide urban planning towards safe areas (Fig.2). The method employs field and laboratory parameters to characterize a region in geological and geotechnical compartments. In this sense, its purposes are to guide urban expansion vectors, to identify potential safe places or otherwise where interventions are required and occupation is not recommended.

4.2 GIDES Method

4.2.1 Introduction

The elementary statement implies that the risk is conditioned by hazard whereas it depends fundamentally on the dynamics associated with the geological phenomena considered [Ko et al., 2003]. Thus, a significant innovation study was conducted to summarize the requirements for a model that predicts the hazard prone areas and the maximum reaches of sediment disasters. In general, the hazard mapping purpose is to locate the critical areas and to improve understanding of the trigger phenomena [Whitworth et al., 2005].

The GIDES project focused on 4 phenomena which caused major human losses and socio-economical impacts in Brazil [CEPED/UFSC, 2013]: slope failures, landslides, debris flows and rockfalls.

The development initiated with bibliographic conceptual alignment based on international and national references [Varnes, 1984; Augusto Filho, 1992; Cruden and Varnes, 1996; COBRADE, 2012; Matsushita, 1999]. During one-year JICA consultants and CPRM/SGB geologists conducted fieldwork to assemble an inventory of natural disaster data. Statistical data analysis and interpretation allowed the definition of potential triggering angles and maximum reaches. These values were confronted with Japanese hazard parameters [e.g. Sabo Frontier Foundation, 2016] and thoroughly discussed on technical meetings and seminars. Due to Brazilian peculiarities such as local geomorphology, tropical conditions, socio-environmental culture, it was necessary to do some adjustments to obtain a more realistic synergic method. These procedures permitted to define (a) sediment disaster ranges for slope failure, landslide and debris flow sediment disasters and (b) a guideline qualification based on instability features.

Risk analysis uses the outcomes of hazard mapping and assesses the likely damage of life and property losses for the elements at risk, accounting for spatial severity and physical vulnerability.

So, the studies took into account the classical equation (Eq.1) of risk analysis [Rebelo, 2003]:

\[ R = P \times V \] (1)

where \( R \) = Risk, \( P \) = Probability/Possibility of sediment-related disaster (Hazard) and \( V \) = Vulnerability, which represents the losses caused to a given element at risk or set of such elements due to the occurrence of a natural phenomenon of a given magnitude [UNDRO, 1979]. The equation 1 correlates risk (R) as being codependent of possibility and
### Table 2: Characteristics of mapping methods in Brazil and Japan.

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>CPRM mapping</th>
<th>Japanese Method</th>
<th>GIDES Method</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Susceptibility</td>
<td>Geotechnical</td>
<td>Risk</td>
</tr>
<tr>
<td>Scale</td>
<td>1:25,000-1:50,000</td>
<td>1:10,000</td>
<td>1:1,000-1:5,000</td>
</tr>
<tr>
<td>Evaluated parameters</td>
<td>Natural topography + Field and laboratory analysis</td>
<td>Natural topography + Anthropomorphpic modifications</td>
<td>Natural topography</td>
</tr>
<tr>
<td>Studied Area</td>
<td>Municipalities, urban planning report</td>
<td>Potential and existing risk areas</td>
<td>City planning guidelines + Potential and existing risk areas</td>
</tr>
<tr>
<td>Targets</td>
<td>Urban Planning</td>
<td>Early-warnings, Alerts, Contingencies, Structural measures</td>
<td>Early-warnings, Alerts, Contingencies, Urban Planning, Structural measures</td>
</tr>
</tbody>
</table>

**Fig.1** One of 313-risk zones in Ouro Preto municipality, Minas Gerais state, surveyed by CPRM in 2016.
phenomena intensity \((P)\) and the vulnerability \((V)\) of each element exposed.

In this context, the equation 1 can be expressed dividing hazard analysis into two phases (Eq. 2). Former hazard modelling based on topographic criteria and maximum reaches for each sediment disaster, named Preliminary Hazard Analysis (PHA). The second phase comprises validation modelling and qualification based on instability features, called Field Hazard Analysis (FHA). Risk assessment is carried out in consolidated urban hazard areas and it is correlated with physical vulnerability of buildings \((V_p)\).

\[
R = P \cdot (PHA + FHA) \times V_p
\]  \hspace{1cm} (2)

The hazard and risk assessment criteria for each sediment disaster will be described in the next section.

4.2.2 Preliminary Hazard Analysis (PHA)

Preliminary Hazard Analysis correlates topographic criteria to the statistical data analysis. These criteria represent a quantitative reference used to identify hazardous topographic triggering thresholds (Table 3) for each sediment disasters \([CPRM/SGB, 2018]\). The criteria adopted were based on Japanese Prevention Act methodology \([e.g. Public Works Research Institute, 1999; Sabo Frontier Foundation, 2016]\). Adjustments were necessary due to lack of data regarding mainly sediment disasters impact forces and strength of Brazilian buildings and some Brazilian peculiarities. The latter due to disorderly occupation and fragility observed nation-wide. These anthropogenic modifications, such as deforestation, changes in natural landscape \((e.g.:\) cut-and-fill\)), natural drainage flow modifications, modify significantly natural conditions of the terrain and, consequently, the geomorphological predisposition of stability \([BRASIL, 2007]\). Therefore a conservative threshold was assumed.

Once topographic references have been established the efforts were addressed to define maximum transportation reaches and their impacts. Two PHA areas, known as Critical Area (CA) and Dispersion Area (DA) (Table 4) have been established.

4.2.2.1 Slope failure

According to the GIDES field survey described in 4.2.1, from 142 slope failure disasters evaluated, more than 90% of slopes had slope angles equal or superior to 30° and 95% had at least 5 meter height. In addition, 73% of destroyed buildings were located closer than 30 meters from the slope base. Also, in
76% of investigated cases, maximum distance of mobilized sediment was twice of the slope height (2H) [CPRM/SGB, 2018]. As shown previously, the correlations are similar to observed in Japanese sediment disasters [Public Works Research Institute, 1999] and endorsed in Sediment Disaster Prevention Act [Sabo Frontier Foundation, 2016]. Based on this data, critical area was defined comprising prone area (slope angle $\geq 25^\circ$ and height $\geq 5$ m).

The upper limit of the critical area was set 10 meters above the prone area, as a safety condition. The bottom limit of the critical area refers to the equivalent length of slope height or no greater than 30 meters. The dispersion area always distributes on the lower side of critical area. The distance at the bottom limit of the prone area corresponds to twice the slope height or no greater than 50 meters. Figure 3 summarizes the framework for critical and dispersion areas associated to slope failures.

4.2.2.2 Landslides

In Japan, in 80% of study cases, the distance reached by the mobilized sediment from a landslide is equal to the landslide length (L1) or no greater than 250 m [Maruyama et al., 2016]. The analysis of landslide data collected in Brazil allowed to corroborate with the premises adopted in the design of sediment disaster hazard areas in Japanese Prevention Act [Sabo Frontier Foundation, 2016]. The selection of potential landslide areas is based on field past-records of landslides and topographic evidences of landslides. The results point out that the travel distance of the landslide mass with potential to cause destruction of buildings were less than 20% of landslide length (L1) [CPRM/SGB, 2018]. It was assumed for the delimitation of critical area corresponds to the equivalent of landslide length (L1) added 20% of L1-length, as a safety condition. The dispersion area corresponds to 80% of L1-landslide length or no greater than 250 meters. Figs. 4-A and 4-B summarize, respectively, the framework for critical and dispersion areas of landslides.

### Table 3 Topographic criteria reference [CPRM/SGB, 2018].

<table>
<thead>
<tr>
<th>Slope Failures</th>
<th>Debris Flows</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Slope degree $\geq 25^\circ$</td>
<td>• Confinement ratio (length $\geq$ width)</td>
</tr>
<tr>
<td>• Slope Height $\geq 5$ m</td>
<td>• Watershed $\geq 1$ hectare</td>
</tr>
<tr>
<td></td>
<td>• Average valley inclination $\geq 10^\circ$</td>
</tr>
</tbody>
</table>

### Table 4 Preliminary Hazard Analysis (PHA) qualification [CPRM/SGB, 2018].

<table>
<thead>
<tr>
<th>PHA</th>
<th>Critical Area (CA)</th>
<th>Dispersion Area (DA)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>High potential for generating sediment related disasters (SDR). The SDR potential energy exceeds the strength of buildings. It is expected that building located in this area can be destroyed by the force of the event.</td>
<td>Sediment related disasters depositional area. The SDR potential energy may be diffuse and does not exceed the strength of buildings. It is expected that building located in this area can be damaged by the force of the event.</td>
</tr>
</tbody>
</table>

4.2.2.3 Debris flow

The parameters to identify debris flow potential watershed was based on Sabo Division, Sabo Dept. Ministry of Construction, 1988. Nevertheless, 61 debris flow events have been surveyed in Blumenau (SC), Nova Friburgo (RJ) and Petrópolis (RJ) municipalities to evaluate Japanese parameters with Brazilian cases. Field data allowed to identify that debris flows occurred preferentially at first order drainage watersheds up to 1 ha. In this sense this limit was adopted as the smallest watershed area.

As shown in Table 3, potential debris flow valleys must attend some parameters as confinement ratio, comprising elongated-shaped watersheds, and average valley slope higher than 10$^\circ$ [Sabo Frontier Foundation, 2016]. The confinement point corresponds to the beginning of confined section in the uppermost part of the valley. The spread point indicates the transition between transport and deposition conditions of mobilized material during the debris flow. The analysis of Brazilian debris flows revealed that the greatest destructive force is concentrated on steeper
valley sections (at confined section) and inside 40 meters of the main flow axis (at non-confined section). The number of observed buildings destroyed increases considerably for slopes steeper than 7° [CPRM/SGB, 2018]. Based on the field data, critical area was settled as the total extension of the confined section and limited laterally by 20 meters for each main flow channel at non-confined section. The lower limit was considered as 7° of terrain inclination.

After leaving the confined section the transported sediment tends to deposit diffusely without a preferential direction. It was observed at the field surveys, and on studies carried out in Japan [Mizuyama & Shimohigashi, 1985; CPRM/SGB, 2018], that the sediment distributes outside the critical area, at the non-confined section, below the spread point. The sediments preferably spread and deposit at a 60° aperture angle (in fan-shaped). The lower limit corresponds to area steeper than 2° in terrain. Fig. 5 summarizes the framework for defining critical and dispersion areas of debris flows.

4.2.2.4 Rockfall

Rockfalls are highly destructive and complex disaster phenomena. Following detachment the dynamics include sliding, free falling, rolling and bouncing motions [Evans and Hungr, 1993]. They present difficulties for any predictive volume or estimated trajectory and maximum runouts. Rockfall debris accumulates at the slope base as talus deposits.

As shown in Table 3, Japanese method does not distinguish rockfalls from slope failures processes. Empirical models of rockfalls generally correlate topographic parameters and the length of runout zones [Dorren, 2003]. Evans and Hungr (1993) showed that...
maximum runout of rock blocks could be estimated based on shadow angle ($\beta$) taking into account the distance between the top of talus deposit and the farthest rock block. They showed the correlation of block maximum reaches due terrain topography. Field data investigations and statistical interpretations allowed individualization of 3 groups based on slope source area, talus presence and estimated maximum runouts [Dorren, 2015; Ribeiro, 2013; CPRM/SGB, 2018] (Fig. 6).

Table 3 describes the parameters to identify potential hazardous areas. Topographic parameters corresponding to source areas, comprising slope inclinations higher than 50° and minimum of 5 meters slope height. In a more realistic approach, talus deposits were adopted as a generic geomorphological element ranging from 20° to 50° inclinations that can be or not accompanied by a rock escarpment. Talus has a considerable influence on the rock blocks runout and on its trajectories [Kirkby and Statham, 1975; Statham, 1976].

Figure 7 shows the 3 groups with their specific parameters that define the critical and dispersion areas. These values are arranged in Table 5.

Preliminary Hazard Analysis (PHA) shall comprise critical and dispersion areas for each sediment related disaster. The result of the PHA will be used in the field surveys to determine hazard qualification as described in the next section.

4.2.3 Field Hazard Analysis (FHA)

Most sediment disasters occur in areas previously affected by instabilities and few occur without any early evidence [Bell, 2007]. These evidences are commonly found in the triggering areas [Bell, op.cit.], i.e., critical areas. Therefore, classification must be done in those areas.

Attention was focused on a qualitative assessment at
critical areas where disasters have been triggered. Field Hazard Analysis (FHA) qualifies the terrain into 4 hazardous classes (Table 6) based on qualitative instability features encountered at the terrain [CPRM/SGB, 2018]. Every critical area has a minimum potential condition to start sediment disasters. Hence, critical areas without any instability evidence shall be considered to be graded as moderate hazard class (P 2). Table 6 describes the hazard classes for critical and dispersion areas, bearing in mind that medium hazard critical areas (P 2 c) does not present any instability feature at the terrain. It is noteworthy to point out that dispersion areas adjacent to P 2 c is the only scenario in which low hazard class (P 1 d) will be applied.

4.2.4 Risk assessment

In Brazil there are no systematic studies that can be used to quantify the resistance of structures (buildings) to forces exerted by the sediment phenomena nor to support evaluation of vulnerability degrees for each phenomenon. As a consequence the term “physical vulnerability” (Vp) (Eq. 2) were adapted from BRASIL, 2007 classes. The qualification considers building materials (wood, masonry or both) and the severity of structural damages based on visual examination. At present evaluation there are 4 vulnerability classes of which the lowest (V 1) it is only employed at buildings with technical report ensuring its structural integrity due GMM damages. The medium vulnerability class (V 2) refers to masonry buildings with no evidence of structural damage regardless of technical report. Buildings shall be considered as of high (V 3) vulnerability when have any kind of structural damage or they are built with

![Fig.7 Preliminary hazard analysis for groups I (A), II (B) and III (C) of rockfalls.](image)

<table>
<thead>
<tr>
<th>Table 5 Framework for defining rockfall critical and dispersion areas.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Group</strong></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>I</td>
</tr>
<tr>
<td>II</td>
</tr>
<tr>
<td>III</td>
</tr>
</tbody>
</table>

* Block deviation path in the direction of the largest gradient of the terrain [Agliardi and Crosta, 2003]. The block deflects laterally from its initial point about 20° to one side or the other [Azzoni et al, 1995].

** The letter H corresponds to the maximum height of the slope.
wood or mixed materials (masonry-wood). The very high (V 4) vulnerability are those buildings with its structure highly damaged or are precarious wooden constructions.

It is noteworthy that the analysis must be carried out inside hazard areas (both critical and dispersion areas). At the end risk assessment is established considering GMM records, identification of movement processes (potential or installed), delimitation of movement reaches, recognition of instability features expressed at terrain and buildings vulnerability qualification.

Table 7 shows risk assessment correlating hazard and vulnerability matrix [CPRM/SGB, 2018]. Risk classes definitions were adapted from Ministério das Cidades, 2007 (Table 8).

### Table 6 Field Hazard Classes [CPRM/SGB, 2018].

<table>
<thead>
<tr>
<th>Hazard</th>
<th>PHA</th>
<th>FHA</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>P1</td>
<td>DA</td>
<td>P1d</td>
<td>Absence of geological-geotechnical conditions that may trigger sediment disasters. Potential energy related with events occurs dispersedly; it means that the energy generated by sediment disasters does not exceed the buildings strength. It is not expected to find evidence of instability or event records in terrain; however, it may appear sparsely. During normal rainfall conditions the possibility of sediment related events is low.</td>
</tr>
<tr>
<td>P2</td>
<td>CA</td>
<td>P2c</td>
<td>Existence of geological-geotechnical conditions and/or predisposing features that may trigger sediment disasters. Potential energy related with events could occur concentrated; it means that the energy generated by sediment disasters may exceed the buildings strength. Evidence of instability or event records may appear sparsely in terrain. During normal rainfall conditions the possibility of sediment related events is moderate.</td>
</tr>
<tr>
<td></td>
<td>DA</td>
<td>P2d</td>
<td>Absence of geological-geotechnical conditions that may trigger sediment disasters. Potential energy related with event occurs dispersedly; it means that the energy generated by sediment disasters does not exceed the buildings strength. It is not expected to find evidence of instability or events records in terrain; however, it may appear sparsely. During normal rainfall conditions the possibility of sediment related events is moderate.</td>
</tr>
<tr>
<td>P3</td>
<td>CA</td>
<td>P3c</td>
<td>Existence of geological-geotechnical conditions and/or predisposing features that may trigger sediment disasters. Potential energy related with event occurs concentrated; it means that the energy generated by sediment disasters may exceed the buildings strength. It is expected to find instability evidences or event records in terrain. During normal rainfall conditions the possibility of sediment related events is high.</td>
</tr>
<tr>
<td></td>
<td>DA</td>
<td>P3d</td>
<td>Absence of geological-geotechnical conditions that may trigger sediment disasters. Potential energy related with event occurs sparsely; it means that the energy generated by sediment disasters does not exceed the building strength. The terrain may show some evidence of instability or event records. During normal rainfall conditions the possibility of sediment related events is high.</td>
</tr>
<tr>
<td>P4</td>
<td>CA</td>
<td>P4c</td>
<td>Existence of geological-geotechnical conditions and/or predisposing features which trigger sediment disasters. Potential energy related with event occurs concentrated; it means that the energy generated by sediment disasters may exceed the building. The terrain shows significant evidence of instability or event records. During normal rainfall conditions the possibility of sediment related events is very high.</td>
</tr>
</tbody>
</table>


### Table 7 Risk assessment correlation matrix.

<table>
<thead>
<tr>
<th>RISK</th>
<th>Vulnerability</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>V1</td>
</tr>
<tr>
<td>P4</td>
<td>P4c</td>
</tr>
<tr>
<td>P3</td>
<td>P3c</td>
</tr>
<tr>
<td>P3d</td>
<td>P3d</td>
</tr>
<tr>
<td>P2</td>
<td>P2c</td>
</tr>
<tr>
<td>P2d</td>
<td>P2d</td>
</tr>
<tr>
<td>P1</td>
<td>P1d</td>
</tr>
</tbody>
</table>

### 5. FINAL REMARKS

The GIDES guideline [CPRM/SGB, 2018] presented in this paper innovates in the sense of bringing a semi-quantitative assessment to the hazard and risk mapping methods in Brazil. Although recognizing the numerous Brazilian methods, it aims to establish simple basic numerical parameters to identify and classify hazardous terrains and buildings at risk. The guideline considers sediment-related disasters occurring on natural slopes and the impact of those events on buildings.

Although the hazard assessment thus far has been poorly discussed in Brazil, it is imperative to insert the subject in the study of natural disasters risk scenarios for better management. The guideline is an instrument to be used by local, state and national government officials, geotechnical professionals, land use planners...
Table 8 Risk Assessment class definitions [Adapted from Ministerio das Cidades, 2007].

<table>
<thead>
<tr>
<th>Risk Class</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>R1</td>
<td>The geological-geotechnical conditions, predisposing features and interventions in the area are low or without potential for inducing sediment disasters. There is no evidence of instability features in the terrain. During normal rainfall conditions occurrences of destructive events are not expected.</td>
</tr>
<tr>
<td>R2</td>
<td>The geological-geotechnical conditions, predisposing features and interventions in the area are moderate for inducing sediment disasters. There are some evidences of instability features in the terrain. During normal rainfall conditions, the possibility of occurrences of destructive events is low to moderate.</td>
</tr>
<tr>
<td>R3</td>
<td>The geological-geotechnical conditions, predisposing features and interventions in the area are high for inducing sediment disasters. There are some significant evidences of instability features in the terrain. During normal rainfall conditions the possibility of occurrences of destructive events is high.</td>
</tr>
<tr>
<td>R4</td>
<td>The geological-geotechnical conditions, predisposing features and interventions in the area are very high for inducing sediment disasters. There are evidences of massive instability features in the terrain. In critical conditions, it is impossible to monitor the process evolution given its high advanced stages. During normal rainfall conditions, the possibility of occurrences of destructive events is very high.</td>
</tr>
</tbody>
</table>

Fig.8 Hazard maps of Braço do Norte (above) and Herval D’Oeste (below) municipalities at Santa Catarina state.
and project managers.

The hazard maps are an important decision-making tool useful for the public and private sectors in promoting actions for risk management but mainly to assist in territorial and land use management and policies. It is a helpful support for drawing contingency plans and early-warning alerts every time that non-structural control measures (prior evacuation) are possible to be applied in emergency preparedness and prevention. In addition, it can be used as basic information to design structural measures on prime hazardous areas.

Effective hazard management sediment disaster have to be done mainly to reduce social and economic losses. This shall be accomplished if the hazard maps resulted in restrictions, regulations or prohibitions of urban development in critical areas.

During the project, as a parallel issue, a semi-automatic computational GIS-tool that allows to run hazard models (PHA-phase) was developed in a short – time period. The tool uses some topographic criteria to identify potential areas and outline maximum distance reaches for each sediment-related disasters, classifying them in critical and dispersion areas, as shown in section 4.2.2.

Geological Service of Brazil (CPRM/SGB) has been making efforts to insert hazard mapping in governmental risk reductions programs. Recently, it was signed an agreement with the Government of the State of Santa Catarina where the hazard method [CPRM/SGB, 2018] has been applied in five municipalities. Data acquired there indicated reasonable results (Fig. 8).

On February 17 and 18, 2019, according to the National Center for Monitoring Natural Alerts and Disasters (CEMADEN), torrential rains hit Guaramirim, Santa Catarina state (Brazilian South region), triggering 31 slope failures events. The accumulated precipitation measured was 206.2 mm/48 h. CPRM/SGB had carried out hazard assessment in January of 2019. The comparison between the affected areas and the hazard mapped areas showed an correlation with 89% accuracy.

The Hazard and Risk Assessment Guideline [CPRM/SGB, 2018] has been developed at the same time as similar guidelines prepared by other counterparts of GIDES project concerning risk management. Some concepts and detailed inputs have interchanged connections. For more information access: https://www.jica.go.jp/brazil/portuguese/office/publications/index.html

The presented paper which describes the development of a new method for gravity mass movements (GMM) hazard mapping in Brazil highlights the importance of international cooperation.

In 2017, GIDES project was awarded the UN Sasakawa Award sponsored by United Nation Office for Disaster Risk Reduction (UNISDR) and by JICA.

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