Methodology for the implementation of a Japanese technique adapted to the national reality for the elaboration of a simplified mapping of areas susceptible to the occurrence of debris flows in Brazil, aiming at the installation of SABO structures

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1. Introduction

Brazilian Government and JICA signed the "*Project to Improve Technical Capacity in Structural Measures against Gravitational Mass Movements with a Focus on Building Resilient Cities in Brazil*", named SABO Project. It aims to develop a technical manual of guidelines for projects elaboration and the construction, maintenance, and operation of Sabo structures.

Within this Project, Brazilian team works on an adaptation of the JICA Project proposal methodology for the simplified mapping of areas susceptible to the occurrence of debris flows, more suited to the technical and financial reality of most Brazilian municipalities, that have no funds to acquire ArcGIS licenses and few knowledge to deal with foreign data and languages.

Public administrations in Brazil are used to deal with insufficient financial resources for constructing all necessary infrastructure. Thus, a technical prioritization system is important for the decision-making process, contributing to an optimized budget execution.

It is important to highlight that this work aims to provide a mapping of potentially suitable locations for the implementation of Sabo structures, and is not, and does not replace, the regular risk mapping process, dealt with in the GIDES manual, which is still required.

2. The JICA project proposal methodology

Using ArcGIS software, the slope of the thalwegs is used to define hazard areas. The upstream sections in mountainous regions with a slope equal or above 10° correspond to the area of debris flow generation. The sections with a slope under 10° and above, or equal to, 2° correspond to the deposition area, indicating the potentially affected area. Sections with a slope of less than 2º correspond to unaffected areas.

The thalwegs lines are obtained from a Digital Elevation Model (DEM) from 3D ALOS World images, with a spatial resolution of 30 meters. The hydrology is extracted using a mesh parameter of 72 pixels (72 x 30m x 30m = 64,800m², or 0.0648 km²). The thalweg lines are converted into points that extract the slope degree of the respective location. Each point is assigned with a color according to its inclination: red within the debris flow generation section; green within the debris flow deposition section and blue within unaffected section.

NASA's *Downscaled Population Base Year and Projection Grids Based on the Shared Socioeconomic Pathways* is used to select relevant thalwegs to work on, according to higher demographic concentration.

Moving from mountain to city direction, for the hazard area delimitation, the most upstream point to be selected is the first green one after a red point, and the furthest downstream point is the last green point before three consecutive blue points, or the last point to have a respective basin area of less than 5.0 km2 (based on historical data related to debris flow occurrences in Japan, these types of events occur mainly in basins with areas between 0.05 km² and 5.0 km²). All intermediate points are also selected, and a 50 m buffer is generated around these points - distance set based on the actual conditions of debris flow occurred in the disaster of January 2011. This polygon is defined as the hazard area.

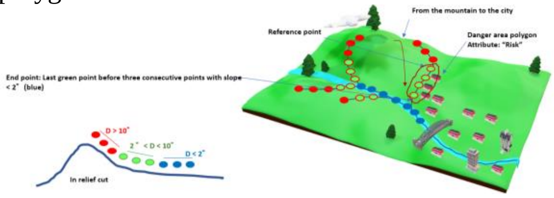

Figure 1-Risk polygon definition

In each of these polygons, the population is estimated based on existing buildings (considering 4.2 habitants per building), and other targets of interest, such as hospitals and schools, are counted.

A method of summing numerical deviations is used to obtain a prioritization number for the areas of influence considering the population and the quantified targets of interest. Then, hazard areas are classified into a priority ranking used in decision-making processes.

3. The adaptation of The JICA project proposal methodology for Brazil

The adapted method is composed by five steps: 1. Images Pre-processing; 2. Hazard area polygons identification; 3. Population estimation; 4. Prioritization of influence areas; and 5. Management. Unlike the Japanese method, all geoprocessing work is performed using Quantum GIS software.

3.1. Images Pre-processing.

For all images and other GIS data to be used, it is adopted the official Brazilian *datum,* SIRGAS 2000. It is also required the use of UTM Coordinates System for the hydrology and slope map elaboration process.

3.2. Risk polygons identification.

The JICA project proposal methodology is applied.

3.3. Population estimation.

Shapefiles of the boundaries of urbanized areas and official data from the Brazilian census are used. Census information is accurate and reliable, but it doesn't provide populational spatial distribution of each sector.

Urbanized areas polygons shapefile shows where people live inside of each census sector, however, populational data is not available in this shapefile. Thus, a geospatial intersection between both layers is required to transfer populational data among them.

Urban density is obtained by dividing the population data by the sum of the extensions of the urbanized areas within each census sector.

The resulting urbanized areas shapefile (with the calculated urban density) is then intersected with the hazard areas shapefile, generating a layer that contains parts of urbanized areas within each hazard area.

The population estimated in each urbanized area part inside of each hazard area is obtained by multiplying their respective urban density and area extension.

The total estimated population living within a hazard area is finally obtained by summing the population estimated in each inner part of urbanized area.

3.4. Prioritization of hazard areas.

Four different approaches were considered: 1) Simple sum; 2) Weighted sum; 3) Normalized sum; and 4) Deviations sum (JICA Project method). The formulae are presented below, considering P – Estimated Population; H – Hospitals; S – Schools; D – Disasters Occurrences.

1) **Simple Sum(SS)**: P + H + S + D;
2) **Weighted Sum(WS)**: $P + 500 \cdot H + 250 \cdot S + 100 \cdot D$;
3) **Normalized Sum(NS)**: $4 \cdot P_n + 3 \cdot H_n + 2 \cdot S_n + 1 \cdot D_n$; P_n, H_n, S_n, and D_n are normalized numbers calculated from: $Xn = \frac{(Xi - Xmin)}{Xmax - Xmin}$, where: X_i is the value correspondent the i[th] hazard area; X_{min} is the lowest value within all hazard areas; and X_{max} is the highest value of all hazard areas.
4) **Deviation Sum(DS):** $P_d + H_d + S_d + D_d$, where P_d, S_d, H_d and D_d are obtained by: $Xd = \left(\frac{10(Xi - \mu x)}{\sigma x}\right) + 50$, where: X_i is the value correspondent the i[th] hazard area; μx is mean value; and σ_x is the standard deviation for all hazard areas.

Higher values correspond to potentially higher priority for the implementation of SABO structures.

3.5. Management.

Discussions about additional criteria to be considered in the decision of where to install the Sabo Barriers, and how to prioritize them, took place during the Sabo project. Besides the parameters considered at the “Prioritization of hazard areas” the following stand out: 1) Data from previous disasters (precipitation, spreading area, casualties, affected households, amount of damage and affected infrastructures); 2) Existence of works; 3) Feasibility of land use; 4) Specific factors that make it difficult to build SABO dams; 5) Existence of request from the city council for the construction of SABO dam; 6) Specific factors that prioritize that area.

3.6. Results

To compare the different prioritization methods used in the adapted methodology, the Deviation Sum approach was used as a reference. For Teresopolis city´s top 20, 60% of the areas of influence prioritized by the Simple Sum method were also in the top 20 of the reference approach. The Weighted Sum method obtained 80% of correspondence, and the Normalized Sum, 90%. For the top 30 (table 01), the Simple Sum adherence increased to 70% and both the Weighted and Normalized Sum reached 100%. Despite the high level of correspondence, it is important to note that the ranking order varies between different methods. The order that most closely matches the reference approach (Deviation Sum) is that of the Normalized Sum.

Table 01: % comparison of overall adherence among all approaches tested:

	Nova Friburgo city (%)				Teresopolis city (%)			
	DS	NS	WS	SS	DS	NS	WS	SS
JPM	47	50	50	50	53	53	53	50
DS	-	87	83	70	-	100	100	70
NS	87	-	100	83	100	-	100	70
WS	83	100	-	83	100	100	-	70
SS	70	83	83	-	70	70	70	-

Regarding the comparison between the results of the JICA Project proposal methodology and the adaptation, it is observed that all four approaches were similar (47 to 53%). Better adherence was expected, however occasional differences in the process of delineating hazard areas made it unfeasible to quantify and to compare some individual results, affecting the final priority ranking. Eventually, a single polygon mapped by the Japanese team was represented as two or three different ones by the Brazilian team and vice versa. Another aspect to be considered is the difference between the population estimation procedure used in both methods.

4. Conclusion

All the steps foreseen were fulfilled for the simplified mapping process of areas susceptible to the occurrence of debris flows, using Quantum GIS and adapted approaches. Additionally, the existing population living in all hazard areas was estimated and served as the basis for calculating the priority number.

The Brazilian approaches of Deviation Sum and Normalized Sum were 100 % equivalent, when the overall 30 first positions are observed, but with internal positions variations. In relation to JICA Project proposal methodology, all prioritization methods had an overall similarity in adherence from 47 to 53%.

A relevant part of the results had a promising level of adherence when compared with JICA Project proposal methodology results, despite the lower level of adherence identified. It is understood that it is a valid method from a technical and financial point of view for municipalities, and that the definition of technical priorities is effective for budget allocation. Thus, the studies and work must continue to improve the adaptation method.

Additionally, differences identified within the risk areas mapping process, reflect the need of higher level of understanding and further training of the methodology by Brazilian team working in the Sabo Project.

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