Morphological evaluation of watersheds and its relation with the debris flow magnitude

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1 BACKGROUND

Fig. 1: Boulder used as part of the wall, in an area where occurred debris flow, in the city of Caraguatatuba, located in the Serra do Mar.

- In Brazil, debris flow occur due the contribution of sediments from landslides to the drainage.
- Many areas already hit by debris flows are still occupied by the population, that ignore the evidences of the process in the landscape (**Fig. 1**).
- The identification of susceptible areas through the morphological parameters and evaluation of the magnitude of past events helps in a better understandment of the process but also in the decision from the governments related to the occupation of those areas by the population.

2 OBJECTIVE

The goal of this research was to estimated the debris flow magnitude and its relation with morphological characteristics of watersheds.

3 STUDY AREA

1967's event: The Disaster of Caraguatatuba

- Serra do Mar is a mountain range located in the southeastern coast of Brazil. The city of Caraguatatuba (**Fig. 2**) is one of the many cities located along the mountain.
- In 1967, rained an average of **946 mm** in march with a critical values in the days 17 and 18, when rained **586 mm/48 hs**, triggering landslides and debris flows (**Fig. 3**);
- Materials mobilized hitted the urban area of the city, in the lowland (**Fig. 4**);
- 120 deaths, **400 houses destroyed** and damage to the highway to the city (**Fig. 5 and 6**);
- ~ **2 millions of tons** of sediments and boulders were mobilized (**Fig. 7 and 8**).

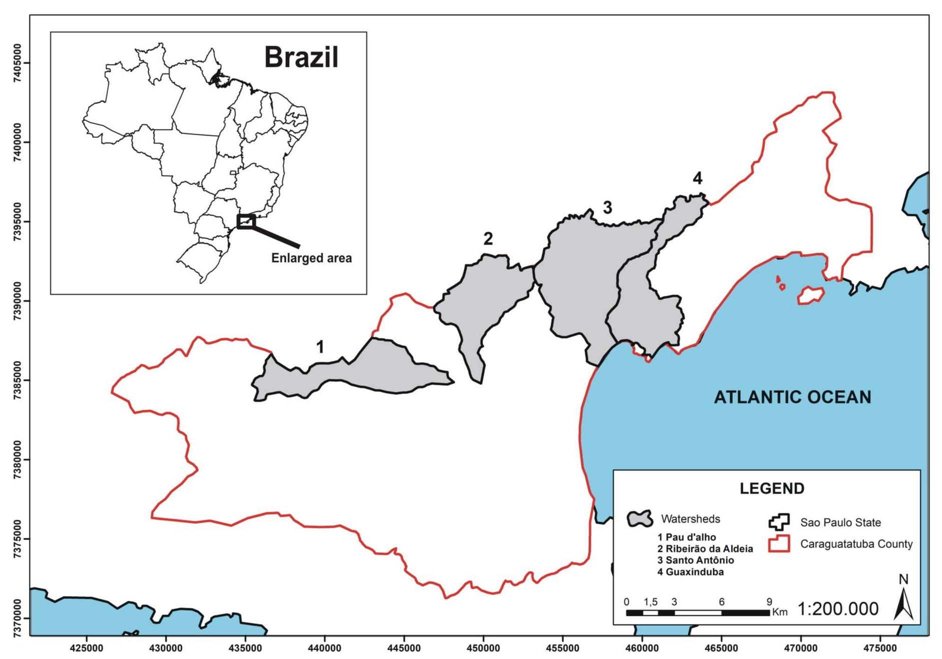

Fig. 2: Location of the study area.

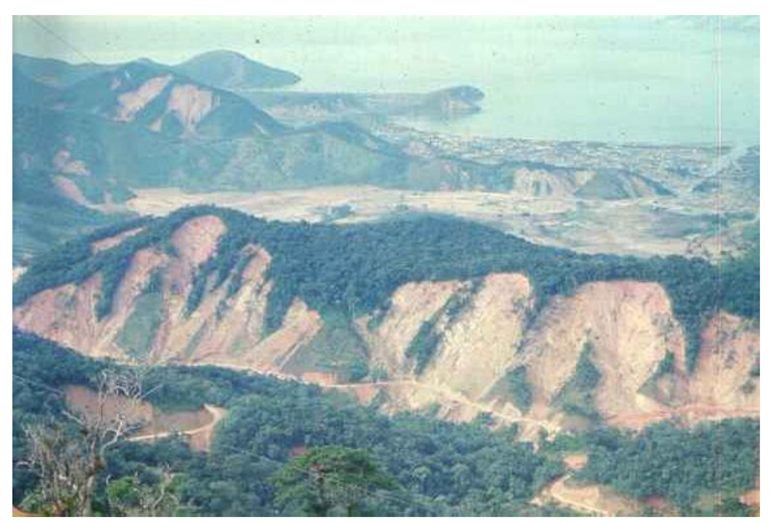

Fig. 3: Landslides and debris flows occurred in Caraguatatuba, in the 1967's disaster. Source: Nogami (1967).

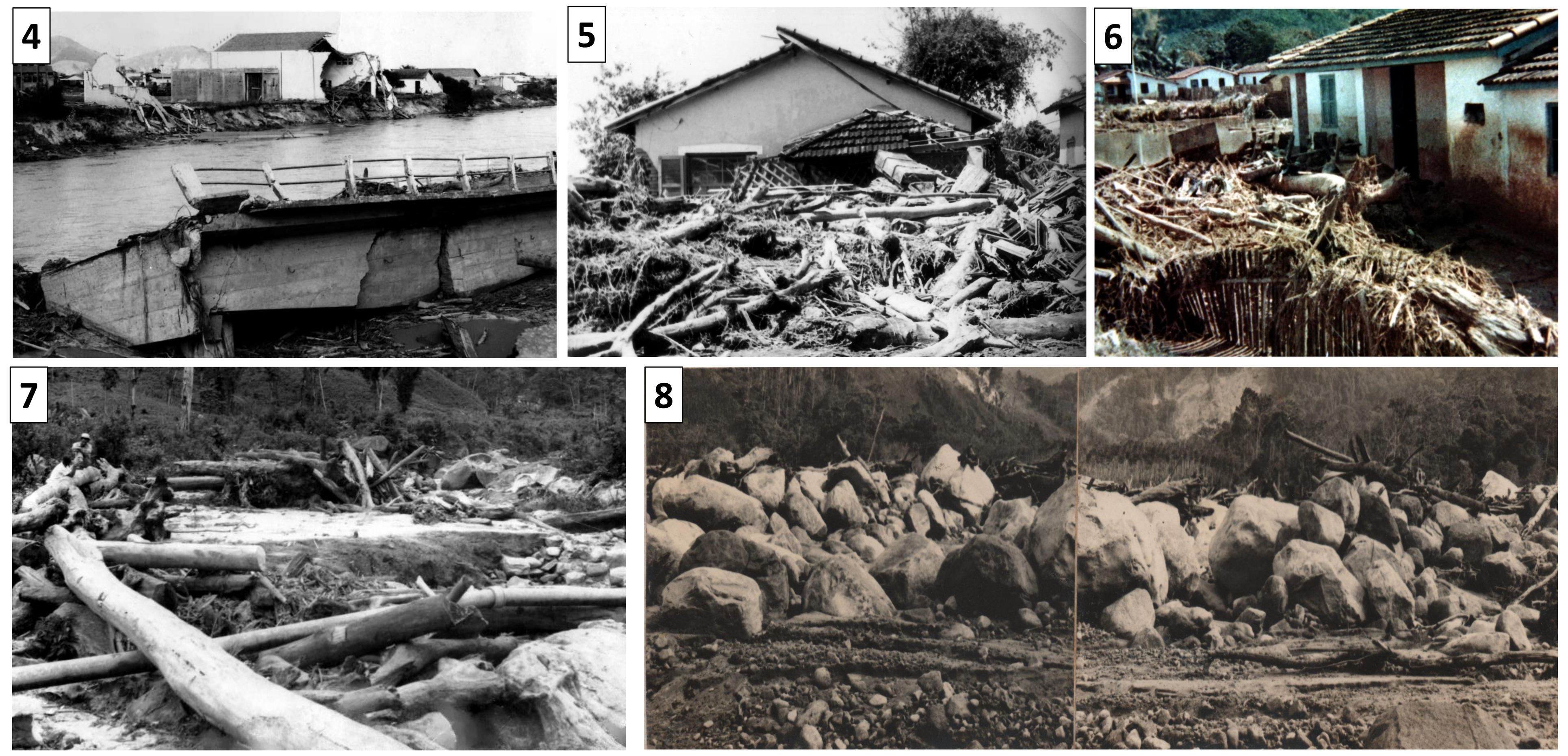

Fig. 4: Bridge and buildings destroyed by the debris flows in downtown. / Fig. 5 and 6: Houses destroyed by the debris flow. / Fig. 7: Deposits composed by large logs, organic matter and boulders. Fig. 8: Debris flows occurred in Caraguatatuba, in the 1967's disaster. Source: Public Archive of Caraguatatuba (1967) (4, 5, 6, and 7) and Olga Cruz (1967) (8).

4 METHODS OF INVESTIGATION

a) Selection of watersheds with occurrence of debris flow. It was made using the morphological mapping from De Ploey and Cruz (1979) and field works (**Fig. 9**).

b) Determination of the characteristics of the deposits in field, using a morphology record (**Fig. 10 and 11**), and the delimitation of the magnitude using the methodology created by Jakob (2005), considering the inundation area (**Table 1**).

Fig. 9: Identification of debris flows's deposits in field.

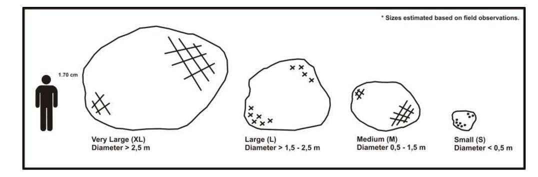

Fig. 10: Classification of the size of the boulders.

Table 1: Magnitude classification of debris flow.

Level	Inundated area (m²)	Potential Consequences
1	$< 4 \times 10^2$	Very localized damage, known to have killed forestry workers in small gullies, damage small buildings.
2	$4 \times 10^2 - 2 \times 10^3$	Could bury cars, destroy a small wooden building, break trees, block culverts, derail trains.
3	$2 \times 10^3 - 9 \times 10^3$	Could destroy larger buildings, damage concrete bridge piers, block or damage highways and pipelines.
4	$9 \times 10^3 - 4 \times 10^4$	Could destroy parts of villages, destroy sections of infrastructure corridors, bridges, could block creeks.
5	$4 \times 10^4 - 2 \times 10^5$	Could destroy parts of towns, destroy forests of 2km² in size, block creeks and small rivers.
6	$> 2 \times 10^5$	Could destroy towns, obliterate valleys or fans up several tens of km² in size, dam rivers.

Source: Modificated from Jakob (2005).

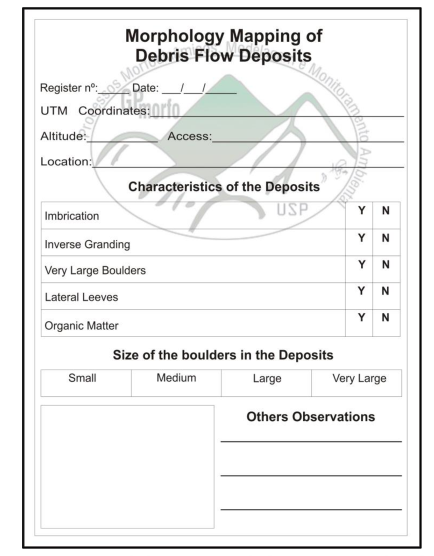

Fig. 11: Field Record for morphological characterization of the deposits.

c) Mapping of the morphological parameters (Area above 25°, Drainage density, Drainage hierarchy, Longitudinal profile, Basin relief, Ruggedness Number and Relief ratio). The parameters were selected due its importance in literature to the occurrence of debris flows (COSTA, 1984; JAKOB, 1996; DIAS *et al.*, 2016).

- SRTM 30m
- Topographic Maps (1:50.000)
- ArcGIS 10.2

5 RESULTS AND DISCUSSIONS

5.1. Morphology of the deposits and Magnitude classification

Deposits with boulders of size **Small** and **Very Large**, highlighting the watersheds **Santo Antônio** and **Guaxinduba**. All deposits's morphology were found in field: **Leeves**, **Inverse Granding** and **Imbrication** (EISBACHER AND CLAGUE, 1984; UJUETA AND MOJICA, 1995; JAKOB, 2005) (**Fig. 12**).

The watersheds showed differents magnitudes:
- **Santo Antônio** was classified with the higher magnitude, **level 3**;
- **Guaxinduba** and **Pau d'alho** were classified in **level 2**.
- **Ribeirão da Aldeia** was classified with the lower magnitude, **level 1**.

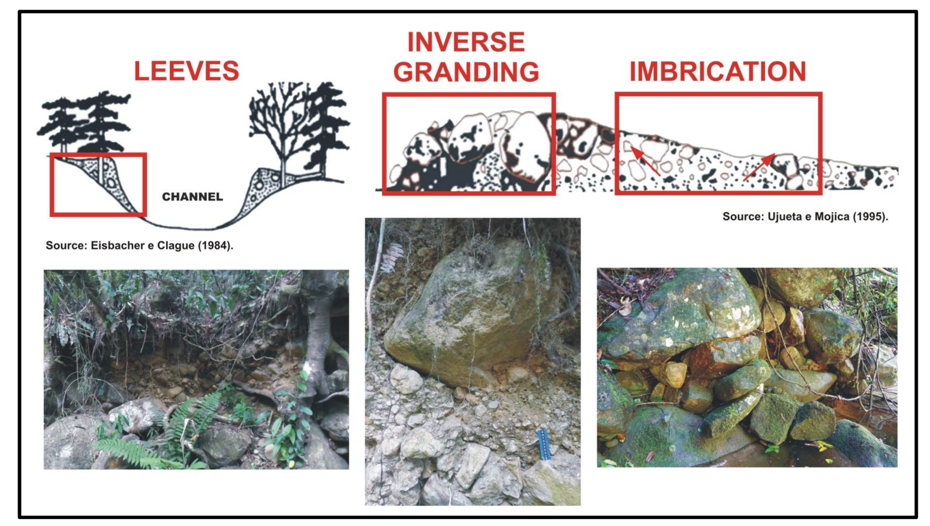

Fig. 12: Morphology types of debris flow deposits found in field.

5.2. Morphology of watersheds

All watersheds showed critical values to the occurrence of debris flow (**Table 2**), highlighting the follow parameters:

Table 2: Results for the morphologic parameters in each watershed.

WATERSHED	Ruggedness Number (dimensionless)	Relief Ratio (m/Km²)	Drainage Density (Km/m)	Basin Relief (meters)	Area above 25° (%)	Drainage Hierarchy (Magnitude)	Altimetric Gradient (m) (Longitudinal Profile)
	MORPHOLOGIC PARAMETERS						
Guaxinduba	3444,1	77,76	3,41	1.010,00	31,4815434	52	320
Pau d'alho	2610,6	91,27	2,27	1.150,09	28,4368885	42	160
Ribeirão da Aldeia	2247,42	111,91	2,47	910,221075	36,3731185	43	114
Santo Antônio	2054,8	94,34	2,2	934,122742	30,6864146	62	326

The Watersheds **Santo Antônio** and **Guaxinduba**, both classified with higher magnitudes, showed high values to the follow parameters:
- **Longitudinal Profile (Altimetric Gradient)**
- **Drainage Hierarchy**
- **Drainage Density**
- **Ruggedness Number**

5.3. Potential consequences forecasted

Compatible with registered damages.
- **Santo Antônio**, classified as **level 3:** destruction of bridges and the highway.

Nível 3: *"Could destroy larger buildings, damage concrete bridge piers, block or damage highways and pipelines."*

- **Guaxinduba**, **Pau d'alho** and **Ribeirão da Aldeia**, were classified with lower levels (**2** and **1**, respectively): small and located damages.

Nível 1: "Very localized damage, known to have killed forestry workers in small gullies, damage small buildings."

Nível 2: *"Could bury cars, destroy a small wooden building, break trees, block culverts, derail trains."*

6 CONCLUSIONS

- The results for the morphological parameters were **compatible with the literature** for occurrence of debris flows.
- The watersheds classified with **higher magnitude** showed **critical values to some parameters**, indicating its importance.
- The methodology of magnitude classification, created by Jakob (2005) was efficient. The potential consequences forecasted by the classification were **compatible with the damages registred in the 1967's event**.
- **In this way, the results showed that it is possible identified critical areas for the occurrence of debris flow using morphological parameters.**

7 REFERENCES

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Acknowledgements