Landslides and Engineered Slopes. Experience, Theory and Practice – Aversa et al. (Eds)

Landslides and morphological characterization in the Serra do Mar, Brazil

H.C. Dias, V.C. Dias & B.C. Vieira
Department of Geography, University of São Paulo, São Paulo, Brazil

ABSTRACT: The aim of this paper is to demonstrate the influence of the morphological and geological parameters in the occurrence of landslides in the Serra do Mar and verify the influence of March 1967 rainfall event to landslides, that was considered one of the most catastrophic in Brazilian territory. The morphological and geological analysis were carried out, respectively, based on Digital Model Elevation (DEM) obtained from LiDAR data, and by digital map at 1.50.000 scale. A landslide scar map was elaborated based on orthophotos from 1967 and 1973. The results may indicate that there is a connection between landslides scar and some morphological classes, such as the occurrence of these features on concave slope with 30° of inclination. These results and land use map may contribute to identify risk areas, reducing the social and economic damage.

1 INTRODUCTION

Serra do Mar, mountain range located in the coastline of the south and southeast regions of Brazil, has been affected by shallow landsliding and debris flows, especially during intense summer rainstorms. Those rainfall events of great intensity occur in summer season, between December and March, which associated to susceptible areas and high density occupation may cause destruction and economic and social lost.

Serra do Mar's origins are related to prominent tectonics processes starting at Cenozoic, with a large diversity of lithologic foundation, such as migmatic and metamorphic associations, besides a lot of igneous complex (Fernandes & Amaral, 1996; Almeida & Carneiro, 1998). Also, it's characterized for being a typical relief of plateau edge, with top level in altitudes between 800 and 1200 m.

In 1967, the municipality of Caraguatatuba was severely affected by mass movement that reached the lower parts of the relief, where there was an area with high density occupation, causing many deaths and homeless, besides damages to local infrastructures, as highways. After that, others more current events occurred in Serra do Mar, in the municipality of Cubatão, São Paulo State, in 1985 and Rio de Janeiro state, in 2011 (Fig. 1).

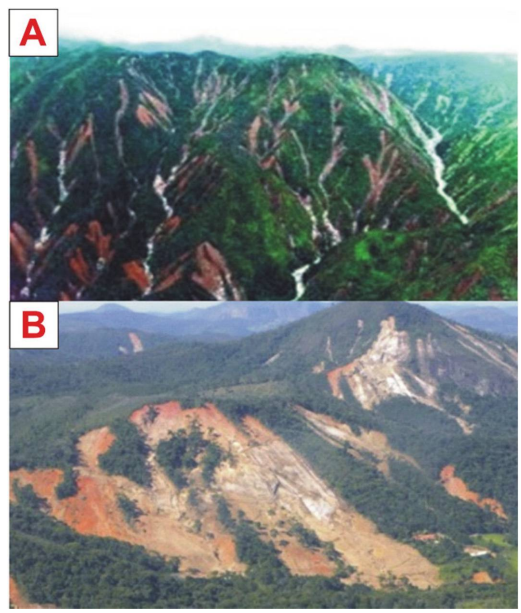

Figure 1. Landslides in Serra do Mar, southeastern of Brazil. A: Serra do Mar - 385 mm/48h (1985); B: Mountain Region of Rio de Janeiro - 300 mm/48h (2011). Source A: Technology Research Institute of the São Paulo State. B: GPMorfo.

From the morphological point of view, slope angle can influence on the slope stability, once as the angle increase, the soil or unconsolidated materials tension also increases. Thus slopes with angle above 30º are more susceptible to landslides (Fig. 2). The curvature can indicate areas with preferential accumulation of rainfall, which turns this parameter very important in the evaluation of the slopes dynamics, since the occurrence of concave

Figure 2. Landslides in steep slopes Caraguatatuba, in 1967. Source: Public Archive of Caraguatatuba.

Figure 3. Landslides occurred in concave slopes in 1967. Source: Marcelo Gramani (personal archive).

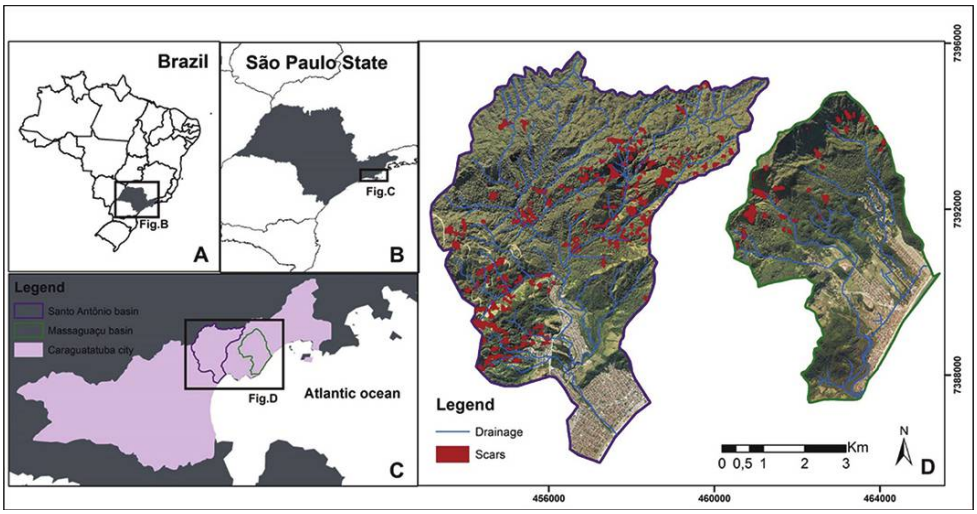

Figure 4. Location of basins, in São Paulo state and Caraguatatuba city.

slopes (Fig. 3) indicate areas where soil saturates faster than in other curvature, triggering runoff and consequently influencing directly in the occurrence of landslides (Selby, 1993).

The geological structure and lithology defines the types of rocks with more occurrence of landslides, which can help defining the instability degree of the slopes (Pachauri & Pant, 1992).

The study of the morphological and geological characteristics is necessary, supporting susceptible analyses and helping to predict mass movement (Selby, 1993). Thus, the aim of this paper is to demonstrate the influence of the morphological (Curvature, hypsometry, slope and aspect) and geological (Lithology and structure) parameters in the occurrence of landslides in the Serra do Mar, Brazil.

2 STUDY AREA

The study area is composed of two hydrographic basins, named Santo Antonio (~40 km²) and Massaguaçu (~20 Km²), located in Caraguatatuba (Fig. 4), which were selected due to their magnitude on 1967 event. The major basin was severely affected by the 1967's landslides and characterized for having large valleys along the escarpment, with very dense drainage (Cruz, 1974 the smaller was also affected by landslides, however with minor intensity,with medium drainage density, extended valleys, and low dissection index, with gentle slope break.

The geological structure and lithology reveals the predominance of granite and gneiss and a large occurrence of tectonic faults and fractures, with general orientation NE-SW, revealing a high struc-

tural control, especially in Santo Antonio basin, influencing in the drainage, generating V-shaped valleys (Cruz, 1974).

Trees with 15 to 40 m height characterize tropical rainforest cover. Although its being a forest with fast regeneration, the landslides scars by 1967's are still evident in the landscape, once the vegetation that has developed in those locals are very different from the rest of the forest, being composed of some kind of bracken (Gleichênia). This region is one of the most humid areas in Brazil, once that in winter season it does not stops raining, as occurs in the most part of the country, just rainfall drop when compared with the summer season.

3 1967 EVENT

The 1966/1967 summer rainstorms provocated one of the biggest catastrophic events of Brazil related to the occurrence of mass movement, It was characterized by rainfall above average in a short period time (584.8 mm / 48 h). Material from the landslides reached the straems and the huge water volume transported them toward the urban area, resulting in several damages to the population and local economy, destroying residential and commercial areas, highways and industries (Fig. 5) (Cruz, 1974).

The rainfall in Caraguatatuba among the years 1965–2011 between December and March (Fig. 6) shows a high rainfall rates typical of the city, highlighting the years 1966–1967, where total rainfall exceeded 1400 mm.

Cruz (1974) related that all the types and forms of landslides occurred in the city, with a total of two million tons of materials. Gramani (2001) organized a sequence of occurrences of March 18, 1967, splitting the events in four phases: 1st. Ini-

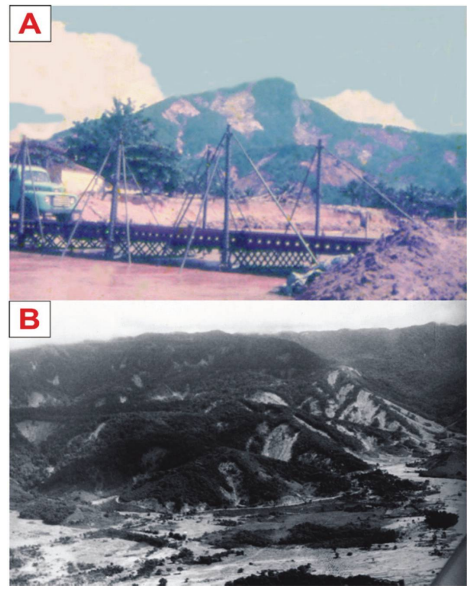

Figure 5. Landslides in Caraguatatuba, 1967. A: Jaraguá Hill and B: Aerial view of the landslides. (Source: Public Archive of Caraguatatuba).

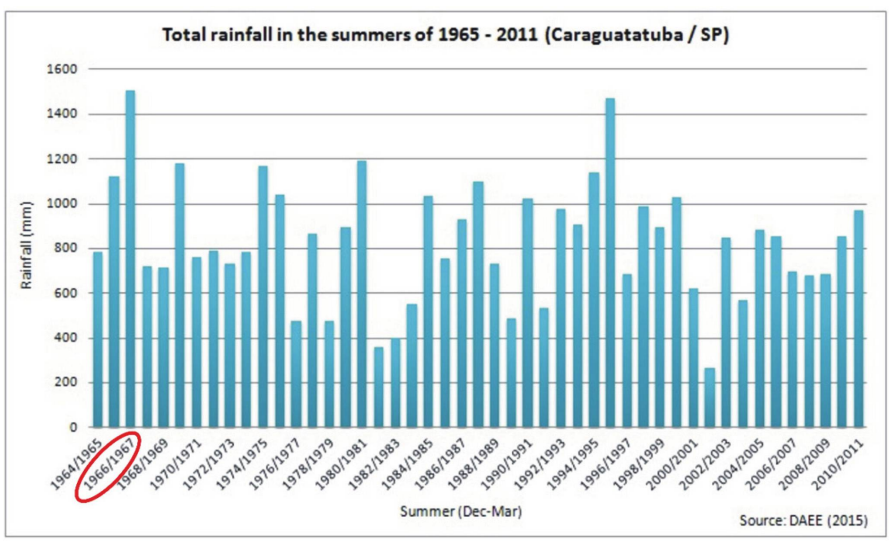

Figure 6. Total rainfall in the summers of 1965–2011 in Caraguatatuba, highlighting the summer of 1966–1967.

tial flood; 2nd. Landslides; 3rd. Debris Flows; and 4th. Flood by blocking.

4 METHODS

4.1 *Morphological and geological maps*

To reach the aim of this research it were produced morphological and geological maps, such as curvature, hypsometry, slope and aspect maps, using a high-resolution (5 m^2) digital elevation model obtained from LiDAR technology (EMPLASA, 2010). The detailed geological map was produced by scanning the Mineral Resources Research Company (CPRM) map in scale 1:50.000 from the Caraguatatuba city.

The analysis of the influence of morphological and geological parameters on the distribution and magnitude of landslides was made thru the correlation between the maps from morphological and geological and the map with landslides's scars from the 1967 event, elaborated from orthophotos 1:20.000 scale (Fúlfaro et al. 1976; Forest Institute, 2000).

Finally, a qualitative analysis was made to inferring landslides occurrence patterns in the morphological and geological different classes in the maps. Table 1 presents the classes of the morphological maps. These classes were selected based on geomorphological characteristics and researches in literature. All procedures were made using ArcGIS 10.2.

Table 1. Morphological and Lithological maps and classes.

Map	Classes
Curvature	Concave
	Straight
	Convex
Slope	0–10°
	10–20°
	20–30°
	> 30°
Aspect	North
	Northeast
	Northwest
	South
	Southeast
	Southwest
	West
	East
Elevation	0–200 m
	200–400 m
	400–600 m
	600–800 m
	> 800 m
Lithology	Paraibuna Complex
	Caraguatatuba Granitoids
	Parametamorphic Rocks
	Unconsolidated Sediments

5 RESULTS AND DISCUSSION

Santo Antônio basin has a structural control with faults and fractures (NE-SW) which may influence in mechanical and hydraulic discontinuities acting as preferred alteration paths, which frequently affect the hydrological dynamics of groundwater flows on the slopes and can possibly trigger landslides (Fernandes & Amaral, 1996; Hart, 2007).

Based on a qualitative analysis of geological map (Fig. 7) is possible to deduce a great number of landslides scars (about 80%) in Granitoids Caraguatatuba, where occurs Biotite-granite gneiss predominantly, characterized by presence of biotite, micaceous mineral, that cleaves more easily. Thus, this factor and the granite fractures together can establish site to occur landslides. In Massaguaçu basin 100% of scars occurred in Granitoids Caraguatatuba, such difference in relation with the first basin, can be result of the absence of faults and fractures. So, we found here, in Santo Antonio basin, more relationship between lithological features and landslides

There are variances between both basins related to curvature, hypsometry, slope and aspect. First, in both basins the slope angles >30° were more affected by landslides (Fig. 8). Moreover, in Massaguaçu basin the angles >30° are concentrated in northern site of the basin, and in the Santo Antônio basin, the same angles are more spread, with a minor concentration in the middle area of the basin.The most part of the Massaguaçu basin is located in areas between 200 m while in Santo Antônio basin these values varied, with occurrence of maximum elevation (200 m) only in the south central portion toward the river mouth. The rest of the area was characterized by elevations between 350 m and 935 m in the northern portion, reaching the plateau.

About curvature, we can observe that in both basins most part of landslides scars are concentrated in concave profiles, but in Massaguaçu there are more straight profiles, while in the Santo Antônio these areas occur only in south part.

In general, both basins have similar characteristics about most likely areas of occurrence of landslides. The difference of magnitude probably occurred due to the morphological and geological differences.

In Santo Antônio basin, the faults and fractures, the angle >30° and elevations above 350 m may indicate greater susceptibility to landslides. The same results were identified by other authors

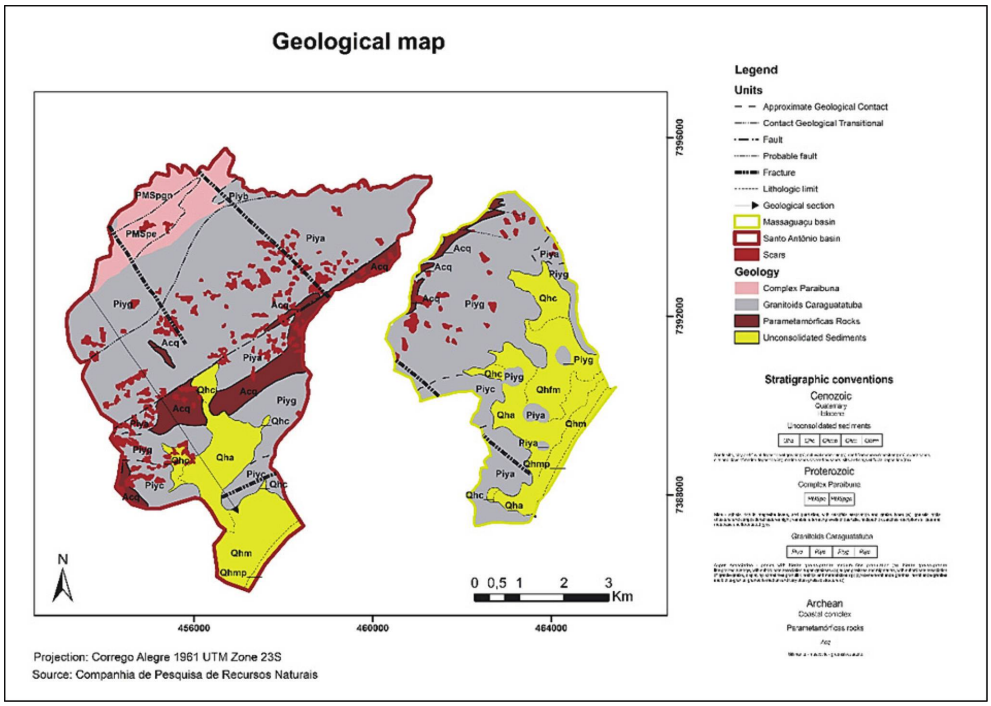

Figure 7. Geological map for Santo Antonio basin and Massaguaçu basin.

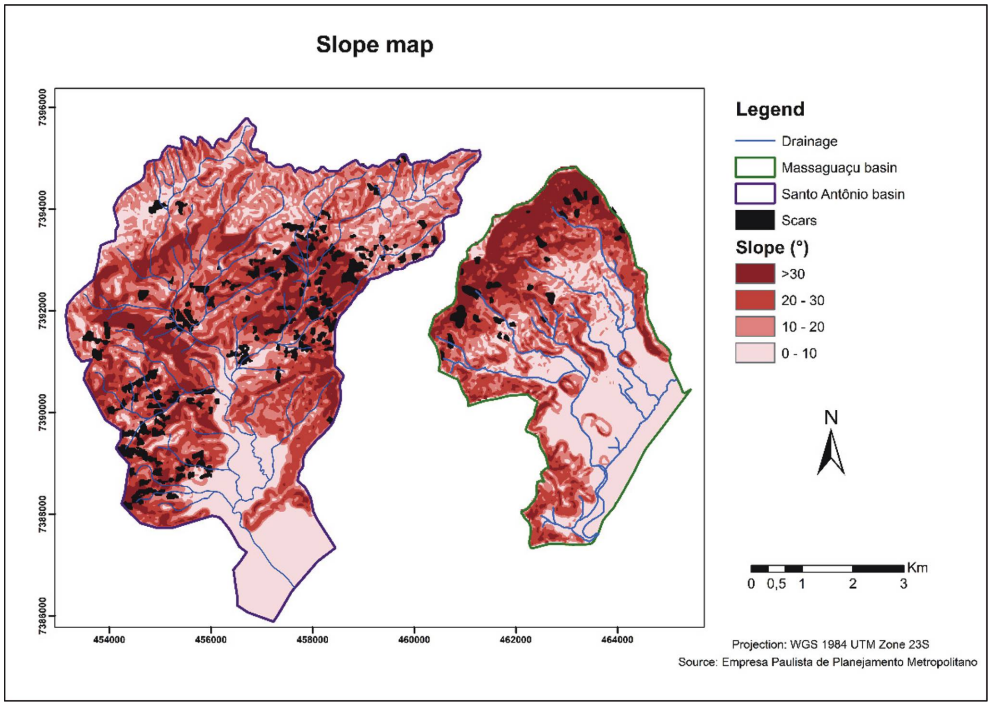

Figure 8. Slope map of Santo Antonio basin and Massaguaçu basin.

such as Sidle et al. (1985); Pachauri & Pant (1992); Lee & Min (2001) and Lan et al. (2004). Pachauri & Pant (1992), for example, identified susceptible areas with faults, fractures and slopes >35°. Lee & Min (2001) confirmed the high probability in angles 25° and lastly, Lan et al. (2004) defined the occurrence of landslides in angles >30°.

6 CONCLUSION

As shown in this study, some morphological and geological characteristics are very important to understand the nature of the mass movements. The identification and analysis of morphological characteristics of basins and the location of the scars from past landslides can be a good method for identifying potentially unstable areas.

Santo Antônio basin had a greater magnitude in landslides of 1967 event due to its morphological and geological characteristics that are more favorable to such processes in the relationship between landscape, rainfall and geological factors.

Future analysis will be necessary to reach more accurate data about the morphological and geological classes which are more susceptible to occurrence of mass movements.

REFERENCES

Almeida, F.F.M e Carneiro, C.D.R. 1998. Origem e evolução da Serra do Mar. *Revista Brasileira de Geociências* 28:135–150.

Cruz, O. 1974. A Serra do Mar e o Litoral na Área de Caraguatatuba – SP. Contribuição à Geomorfologia Litorânea Tropical. Tese de Doutorado. São Paulo: IG – Série Teses e Monografias nº 11.

Fernandes, N.F. e Amaral, C.P. 1996. Movimentos de Massa: Uma Abordagem Geológico-Geomorfológica. In Guerra, A.J.T. e Cunha, S.B. (Org.). *Geomorfologia e Meio ambiente.* Rio de Janeiro: Bertrand Brasil.

Fúlfaro, V.J., Ponçano, W.L., Bistrichi, C.H., Stein, D.P. 1976. Escorregamento de Caraguatatuba: expressão atual e registro na coluna sedimentar da planície costeira adjacente. In *1º Congresso Brasileiro de Geologia de Engenharia*, Rio de Janeiro: Anais Rio de Janeiro, Associação Brasileira de Geologia de Engenharia 2:341–346.

Gramani, M.F. 2001. Caracterização Geológico-Geotécnica das Corridas de Detritos ("Debris Flows") no Brasil e comparação com alguns casos internacionais. Dissertação de mestrado. São Paulo: Escola Politécnica da Universidade de São Paulo.

Hart, M.G. 2007. *Geomorphology: Pure and Applied.* London: Allen & Unwin.

Lan, H.X.; Zhou, C.H.; Wang, L.J.; Zhang, H.Y. and LI, R.H. 2004. Landslide hazard spatial analysis and prediction using GIS in the Xiaojiang watershed, Yunnan, China. *Engineering Geology* 76: 109–128.

Lee, S. and Min, K. 2001. Statistical analysis of landslide suscetibility at Yongin, Korea. *Environmental Geology* 40: 1095–1113

Pachauri, A.K. and Pant, M. 1992. Landslide hazard mapping based on geological attributes. *Engineering Geology* 32: 81–100.

Selby, M.J. 1993. Mass Wasting of Soils. In *Hillslope Materials and Processes*:249–355.Oxford: Oxford University Press.

Sidle, R.C; Pearce, A.J. and O'Loughlin, C.L, 1985. Natural factors affecting slope stability. In *Hillslope Stability and Land Use:* 31–72. Washington: American Geophysical Union.