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Stability Index to Hazard Mapping at the Serra do Mar region – A study case of RJ-165, a UNESCO SITE of Paraty (RJ)

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Abstract.

The Serra do Mar region in southeastern Brazil is recognized for its culture, landscape, and biodiversity, as well as for the recurrence of natural disasters. In summer, shallow landslides affect civilians and cause logistical losses on the main highways that serve as access between the coast and the interior of the Brazilian plateau. In this article, the landslides of the last 10 years on the RJ-165 highway in the municipality of Paraty were investigated using the stability index (SINMAP) comparing to the susceptibility map of the Geological Survey of Brazil (CPRM). We found that the SINMAP model can produce more accurate results, however, it is essential to check the results by success and error indexes.

Resumo

A região da Serra do Mar no sudeste brasileiro é reconhecida por sua cultura, paisagem e biodiversidade, e também pela recorrência de desastres naturais. No verão, deslizamentos rasos afetam civis e causam prejuízos logísticos nas principais estradas que servem de acesso entre a costa e o interior do planalto brasileiro. Neste artigo, os deslizamentos dos últimos 10 anos no trecho da rodovia RJ-165 no município de Paraty foram investigados através do índice de estabilidade SINMAP em comparação com o mapa de suscetibilidade do Serviço Geológico do Brasil (CPRM). Foi averiguado que o modelo SINMAP pode produzir resultados mais precisos e acurados, no entanto é fundamental checar tais resultados através de índices de sucesso e erro.

Key-words – Slope stability; Landslide, SINMAP; Paraty; Serra do Mar; Caminho do ouro.

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1. INTRODUCTION

The Serra do Mar, an escarpment system that extends from the Santa Catarina state (SC) to Rio de Janeiro state (RJ) in Brazil (Fig. 1A-B), is commonly characterized by a dynamic condition, and, due it´s predisposing, the recurrence of mass movements is expected as shallow landslides (Cerri et al., 2020). Shallow landslides are deflagrated by events of intense and accumulated precipitation (Tatizana et al., 1987a, 1987b) so they can be reasonably predicted and measures can be taken to reduce risks (Calvello et al., 2015).

Currently, there are government programs based on rainfall monitoring to manage the hazard scenarios, such as the Plano Preventivo de Defesa Civil (PPDC) in São Paulo and Alerta Rio in Rio de Janeiro. These programs use landslide susceptibility maps as the source to identify hazard-prone areas, alongside with rainfall monitoring that indicates when a risky area should be avoided (Lan et al., 2004; Gutiérrez-Martín, 2020).

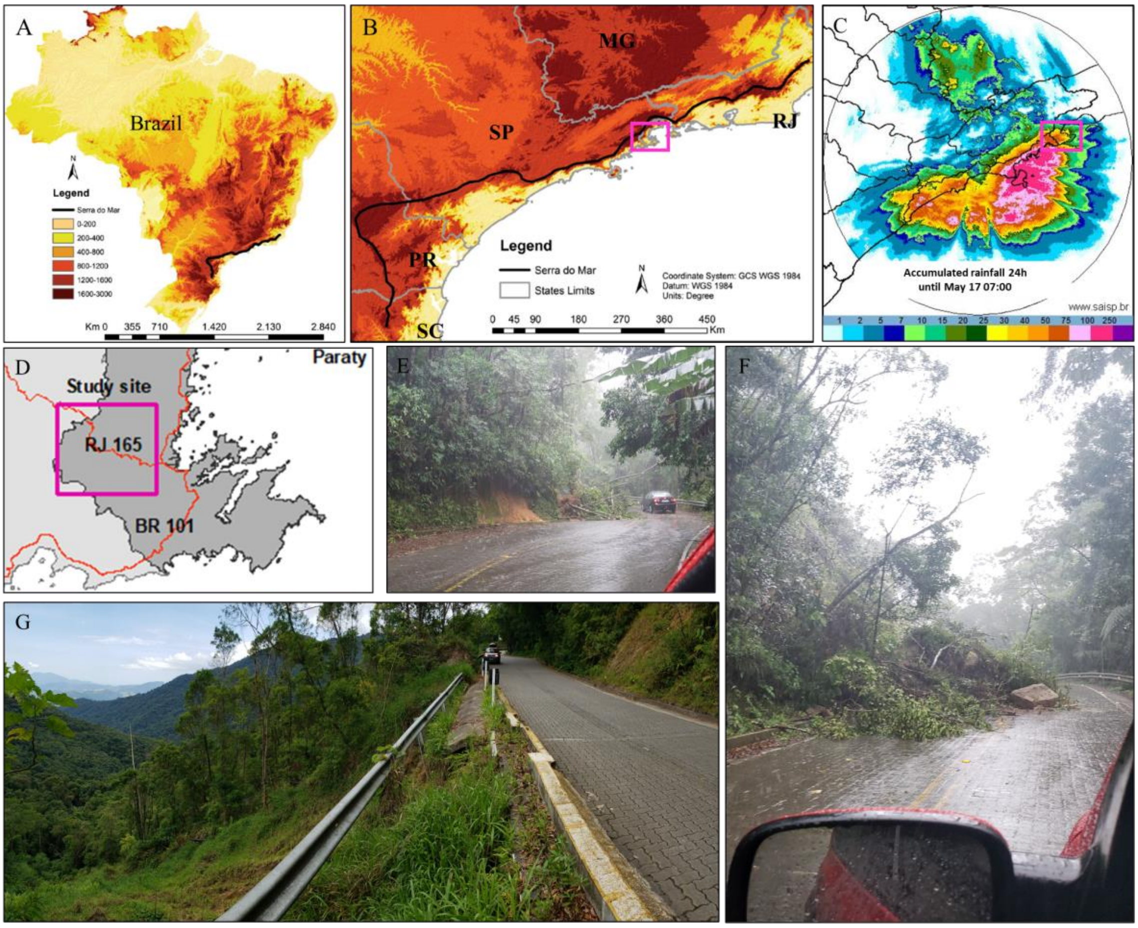


Figure 1. Brazil elevation map and the Serra do Mar location (modified from Vieira et al. 2018) (A – B), rainfall forecast for 16/05/2019 (C), the study site - RJ-165 in the Paraty city (RJ) (D), the mass movements records in RJ 165 in 05/16/2019 (E-F) and it´s damage to highway foundation (G). (Photographs by J.P Monticelli)

Since the 16th of May, 2019, the Rodovia Tamoios, a highway connecting the São José dos Campos and Caraguatatuba cities, has adopted a disaster preventive plan. The plan consists in locking down traffic when there is an accumulated rainfall exceeding 100 mm in 72 hours. In this manner, the highway was closed seven times in early 2019, drawing the attention of the media, the government and the civil community (Portal G1, 2019). Although, this limit can even easily overcome in one day at Serra do Mar domain (Fig. 1C), which in part highlights the need for prevent plans. Two landslides occurred on the Tamoios Highway on May 16, while more than five were recorded at the same time, on RJ-165. No lockdown or general action was carried out by the Civil Defense of Paraty (RJ) or Cunha (SP), where both cities dependent on this access.

Even though these lockdowns have called attention, on the other hand, there are highways, in landslide-prone areas without any preventive plan, where its users are exposed to mass movements, such as RJ-165 in the municipality of Paraty (RJ) (Fig. 1D - G).

Herein, the RJ-165 highway region was investigated based on literature, field mapping, and physically-based landslide susceptibility modeling to highlight its exposition to gravitational movements. The susceptibility map, elaborated by the Geological Survey of Brazil (CPRM, 2015), and one produced by the Stability Index (SI) approach, SINMAP plug-in (Pack et al., 2005) were considered in the back-analysis of shallow landslides that occurred in RJ-165 region in the last ten years. The success and error indexes (SSi and RRi), modified from Sorbino et al., (2010) were calculated aiming to elucidate the spatial correspondence of models with the landslides inventory. The landslide inventory was compiled from Silva (2010) and CPRM (2015), as well as carried out with field mapping and aerial photos.

2. A BRIEF REVIEW OF THE PATHS ACROSS THE SERRA DO MAR AND IT´S IMPLICATION FOR TOURISTIC HAZARD MANAGEMENT

The Serra do Mar, with an elevation greater than 1300 meters, presents itself as a geomorphological barrier between the coast and the interior plateau of the Brazilian (Figs. 1 and 2). Historically, the crossings paths were defined based on a “network” of indigenous trails that connected Brazil, such as the Tupiniquins and the Goyanazes (Ribas, 2003; Santos, 2004). The second, specifically, connected the coastal region of Paraty (RJ) to the interior of Brazil, and during the *gold and coffee* cycles it was paved with blocks by slave labor, the *Caminho do Ouro* (Ribas, 2003). According to Tupinambá et al. (2014), talus bodies served as a source of material for paving.

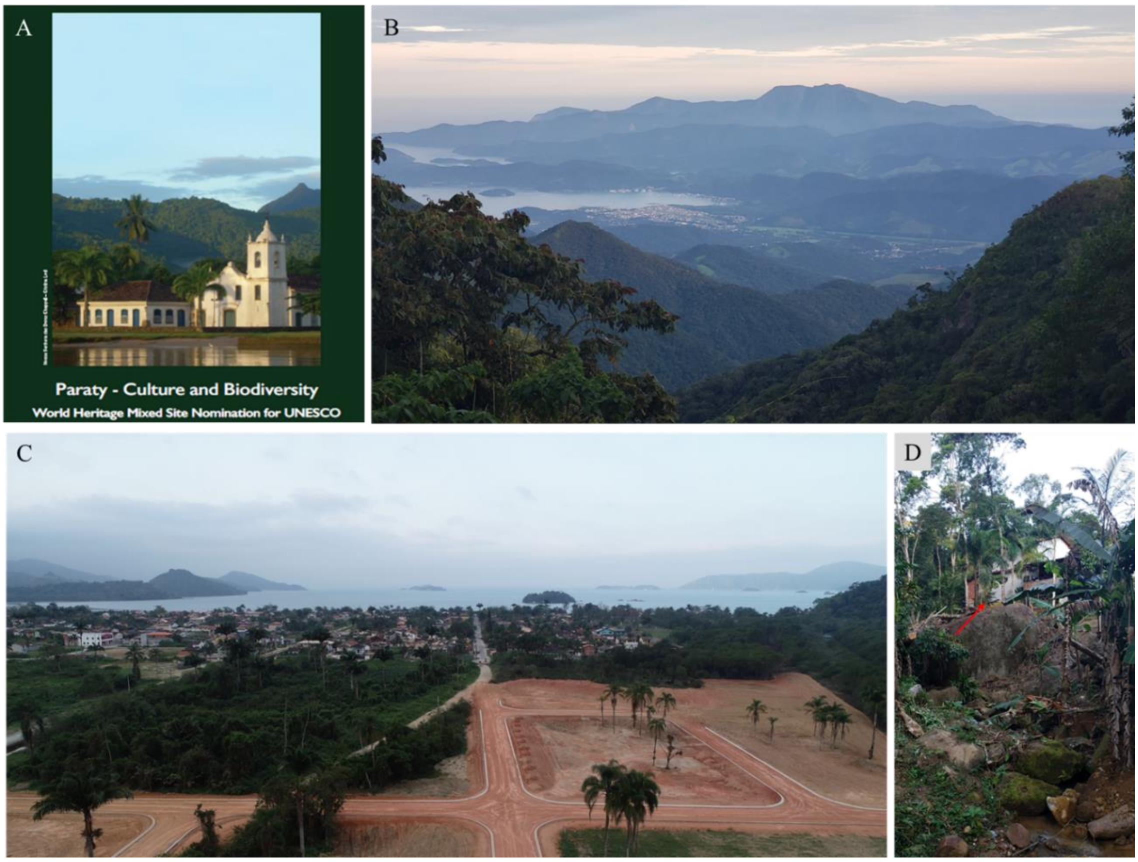


Figure 2. A world heritage site of Paraty (RJ) (A), view from Serra do Mar to Paraty city at RJ-165 (B), land use increasing in plan areas (C) and slope areas (D) (Photographs: J.P Monticelli).

Despite countless reports of the logistical difficulties of the Brazilian colonial period, regarding the Caminho do Ouro, most are related to quagmires, mud, and swamps. In other words, an indication that the stability “was not” disturbed, unlike RJ-165, built following the *Caminho do Ouro* and affected by mass movements regularly. According to Santos, (2004), the road and railway modern transpositions of Serra do Mar (19th to 20th centuries), with projects based on the cutting and embankment technique, were extremely invasive, and under the posture of “winning the Serra at any cost”, corresponded to countless logistical losses. The change in the projects’ design, with the perception of “knowing and respecting the Serra” and its dynamics, led to the adoption of tunnels and viaducts in the elaboration of road transpositions. Inaugurated in 2002, The Imigrantes Highway is a landmark of this history.

In the last ten years, the main roads that provide access and permeate the Brazilian coast are being duplicated or reformed, such as the Tamoios (SP-099), the Rio-Santos (BR-101), and the RJ-165. In particular the last, paved only in 2016, has an archaic design. Consequently, it is subject to mass movements as experienced on May 16, 2019 (Fig. 1).

Moreover, Paraty is located between the two largest metropolitan regions of Brazil, São Paulo and Rio de Janeiro cities, 300 km from the first and 240 km from the second, and encompassing, with the Paraíba Valley, a total of more than 30 million inhabitants. Due to its physical, cultural and historical particularities, a unique tourist’s spot region in Brazil and in the world. Positioned among the four most important destinations for foreign travelers, behind Rio de Janeiro, the Iguaçu Falls and competing in third place with Salvador.

At the end of 2019, the Paraty region was accredited with the title of World Heritage by UNESCO (Unesco, 2019), the first worldwide in scope covering culture and the physical environment (Fig. 2 A - B). The highways BR 101 and RJ 165 are the main alternatives to access this touristic spot. Economic and population growth is already a reality, but it´s unfortunately followed by disorganized government short-term plans converging to badly land uses (Fig. 2 C - D). For the next few years, ensuring conditions of safe housing and access for citizens and tourists in Paraty will prove to be one of the challenges for sustainable development and management of that locality.

3. SUSCETIBILITY MAPPING PROCEEDINGS IN BRAZIL AND SINMAP MODEL

The National Civil Protection and Defense Policy (*Política Nacional de Proteção e Defesa Civil* - PNPDEC), established by Federal Law 12,608 / 2012, brings the principles, objectives, and instruments of how risk management and natural disasters will be implemented in Brazil, to ensure social conditions, economic and environmental measures to guarantee the dignity of the population and guarantee the promotion of sustainable development (Brasil, 2012).

In response to the new policy, the Institute of Technological Research of São Paulo state (IPT) defined the basis for the continuous development of an integrated and upgradable model for the production of susceptibility maps that can generate natural disasters (Bitar et al., 2014). The elaboration of these maps is responsibility of the Geological Survey of Brazil (CPRM). Currently, some Brazilian states, such as Rio de Janeiro, has more than 90% of the municipalities mapped (CPRM, 2020). An example of this news is Paraty and its access to the RJ-165, herein the region of the study site.

The SINMAP is a free Arcgis® plug-in, that aims to serve as a stability hazard mapping tool (Pack et al., 2005). It is based upon the infinite slope stability model accomplished to a hydrological steady state model, used to define a stability index (SI). The SI calculation assumes a uniform distribution of the parameters. The index defines the probability of a stable slope happen per cell of the digital terrain model (DTM). Second the authors, SI reflects the real uncertainty associated with estimating parameters in terrain stability mapping.

The input data comprises the topography and the specific catchment, geotechnical and hydrologic soil parameters. As illustrated in Fig. 3, SINMAP uses the following concept and formula to calculate the stability index (SI). Topographic variables such as catchment area and slope are computed from DTM. The descriptions of SI classes are disposed in Table 1. For more detailed explanations about the infinity slope and hydrological models consult Pack et al., (2005).

The SINMAP approach applies to shallow translational land sliding phenomena. It does not apply to deep-seated instability including deep earthflows and rotational slumps. In Serra do Mar the mechanisms are better explained by transient hydrogeological model, however, several works have been developed with this plug-in, a useful tool to indicate the site of landslides.

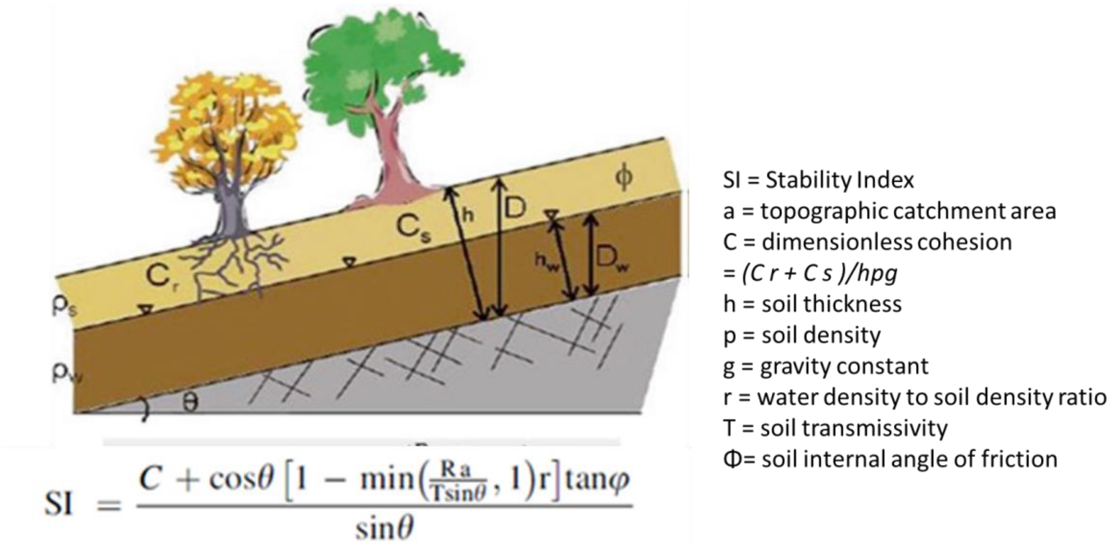


Figure 3. Infinite slope model (Adapted from Pack et al., 2005).

Table 1 - Stability index (SI) classes definitions (Pack et al., 2005)

Condition	Class	Predicted State	Parameter Range	Possible Influence of Factors not Modeled
SI > 1.5	1	Stable slope zone	Range cannot model instability	Significant destabilizing factors are required for instability
1.5 > SI > 1.25	2	Moderately stable zone	Range cannot model instability	Moderate destabilizing factors are required for instability
1.25 > SI > 1.0	3	Quasi-stable slope zone	Range cannot model instability	Minor destabilizing factors could lead to instability
1.0 > SI > 0.5	4	Lower threshold slope zone	Pessimistic half of range required for instability	Destabilizing factors are not required for instability
0.5 > S.I > 0.0	5	Upper threshold slope zone	Optimistic half of range required for stability	Stabilizing factor may be responsible for stability
0.0 > SI	6	Defended slope zone	Range cannot model stability	Stabilizing factors are required for stability

4. MATERIALS AND METHODS

The study site is the region of RJ-165 located in the south of Rio de Janeiro state, Brazil (Fig. 1). It consists of a basement formed by granitic and gneissic rocks cut by small dikes bodies. Usually occurs covered by weathering horizons, transported soil and unconsolidated sedimentary deposits

(CPRM, 2015). The susceptibility map elaborated by the Geological Survey of Brazil was obtained from the Survey's database as well as the topography. A digital terrain model (DTM) was built from this topographic map for the SINMAP analysis following the scale of the CPRM maps, 1:90.000. Then, the morphological parameters (slope angle, aspects, drainages, catchment area etc.) were characterized.

The landslide scars that have occurred in the study site over the last ten years were gathered from the data of Silva (2010) and from CPRM (2015). The aerial photos, with a resolution of 5 meters, from the CBERS 4A satellite dated between 2015 and 2020 were collected. Them composed in pseudo-natural colors, where the scars were identified. Also, the mass movements registered on 05/16/2019 were plotted at the inventory map. Field inspections were made and the landslides positions recorded by a GPS Garmin Etrex 30x. Following the recommendation of Pack et al. (2005) for the analysis, the scars positions were identified by dots at the top of the landslide feature in the GIS environment.

These positions were used to the comparison, in which, the maps attributes were sampled, such as, slope angle, area, rock basement, susceptibility class etc. Besides, for each susceptibility class or index, its area, where the scars occurred, was measured. The landslides per square kilometer were compared with the susceptibility classes obtained from Geological Survey of Brazil and produced by SINMAP susceptibility model.

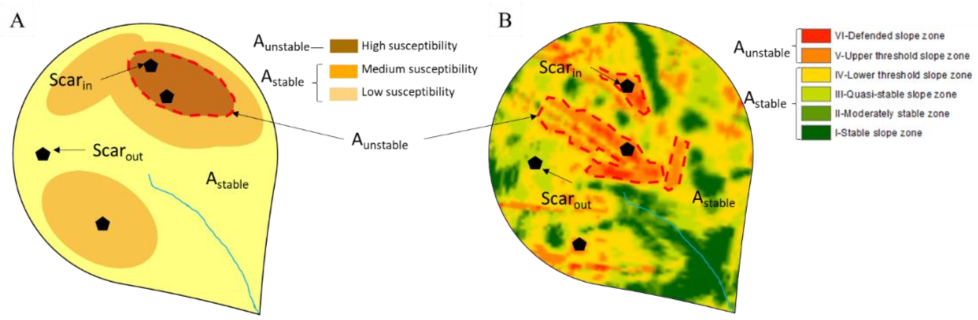
Also, we have compared the relationships between the slope angle and the scars to evaluate the role of morphological features in the susceptibility, SI values and classifications. Seven scenarios were run in SINMAP. The parameters implemented are displayed in Table 2. The data were gathered from Pack et al., (2005), Nery and Vieira (2015) and Amaral Junior (2007).

Table 2 - Parameters values used to Slope Index calculation

Scenario		S1	S2	S3	S4	S5	S6	S7
Depth, h (m)		2	1	1,5	3	3	3	5
T/R (m)	Min	2000	46	68	159	159	300	600
	Max	3000	142	213	497	497	870	1740
C (ad)	Min	0	0.07	0.06	0.15	0.15	0.18	0.07
	Max	0.25	0.96	0.83	0.43	0.43	0.32	0.16
Friction angle (°)	Min	30	34	34	34	32	32	32
	Max	45	39	39	39	45	45	45
Soil density (kg/m^3)		2000	1710	1350	1330	1330	1650	1650
Water density (kg/m^3)		1000	1000	1000	1000	1000	1000	1000
Wetness (%)		10	20	20	20	20	20	20

Obs: data from S1 - Pack et al., (2005), S1, S2, S3 - Nery and Vieira (2015) and S5, S6, S7 - estimated from Amaral Junior (2007). Legend: recharge (R), transmissivity (T), admensional cohesion (C)

The success and error indexes (SI and EI) presented in Sorbino et al., (2010), based in areas, were modified to dot analysis to facilitate the integration with SINMAP. The derived SSi and RRi indexes seek to represent for each map and model their relative efficacy in the back-analysis of the shallow landslides. As presented in Fig. 4, the SSi represents the percentage ratio between the number of scars inside an unstable area normalized by the scar density sum of those areas. While the RRi represents the percentage ratio between the number of scars outside an unstable area. It is assumed that stable and unstable areas represent a group of susceptibility classes from CPRM map and SINMAP models (Fig. 4).



$$SS_i = \left(\frac{n^\circ\ scars\ points_{in}}{A_{unstable}} / \ Scar\ density\ sum \right) * 100 \qquad RR_i = \left(\frac{n^\circ\ scars\ points_{out}}{A_{stable}} / Scar\ density\ sum \right) * 100$$

Figure 4. Adaptation of the success and error indexes of Sorbino et al., (2010) for point-based analysis for the (A) CPRM map and (B) SINMAP model.

5. RESULTS AND DISCUSSION

The site has 152.6 square kilometers, where were registered 98 landslides scars, roughly a scar to 1.6 square kilometer. A clear concentration can be seen in the west portion (Figs 5 and 6). According to the map elaborated by the Geological Survey of Brazil (Fig. 5), for areas classified as low, medium and high susceptibility of landslides, which represent 27, 31 and 42% of the total area, 6, 12 and 80 scars were counted, respectively.

In the histogram in Fig. 5, the scars per square kilometer is shown for landslide zone, as well as for those within of zones susceptible to debris flow and flash flood. It would be possible to find 1.25 scars per km^2 in the high susceptibility class of landslides, and this value decreases for debris flows and flash flood areas. For the medium and low susceptibility landslides zones, the number of scars is less than 0.3 per km^2.

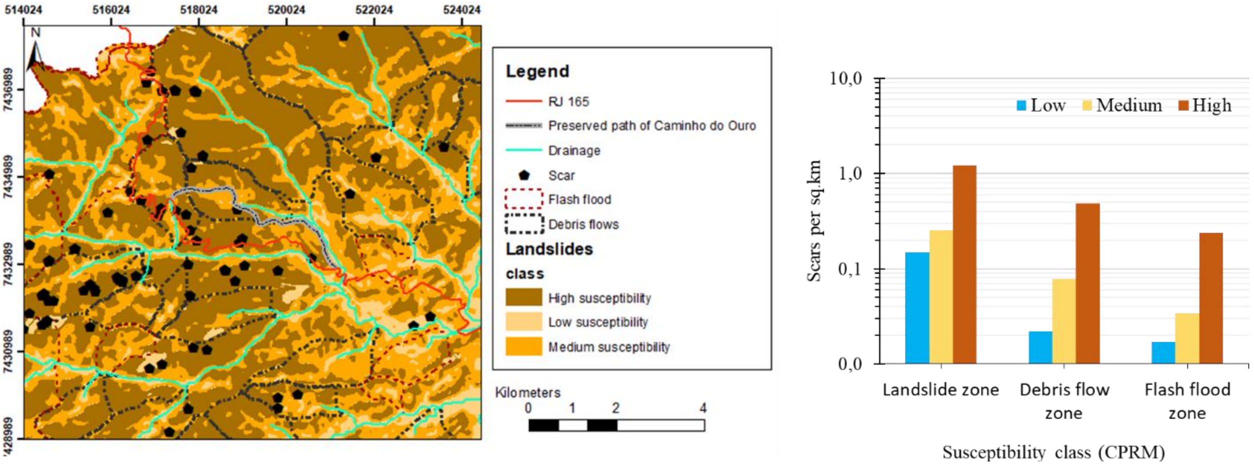


Figure 5. Susceptibility map of CPRM (2015) (1:90,000) and the respectively histograms showing the scars per square kilometer.

Several scenarios have been defined for the SINMAP simulations (Table 2). For each simulated scenario (S1-S7) the scars attributes were collected and scars density was measured (Fig. 6). As an example of the simulations, scenario S6 is presented. The SINMAP simulations based on the concept of infinite slope stability accomplished with hydrological model showed a sensible tool to the back analysis of the shallow landslides in RJ 165, especially for susceptibility classes V and VI (see Table 1).

The highest density of landslides in the upper threshold slope zone (IV) and defended slope (V) classes was also noticed by many authors (Meisina and Scarabelli, 2007; and Nery and Vieira, 2015). Accordingly, with these authors, the aforementioned classes are related with slopes greater than 30°. The relationships between the slope stability index (SI) with some of the morphological features are presented in Fig. 7. It is observed a roughly influence in the SI values in the elevation around 900 to 1550 meters (blue box), which produced a wide SI values variation. For slope angle, the SI values decrease gradually as increases the slope angle to 30°. Between 30° to 55°, the SI shows the lowest values accompanied by a noticeable variation as shown by the blue boxes (Fig. 7). Scar concentration at higher altitudes and at greater slope angles is directly related to the morphology of Serra do Mar, where the higher parts of the mountain retain clouds and fog, increasing soil humidity during rainfall events.

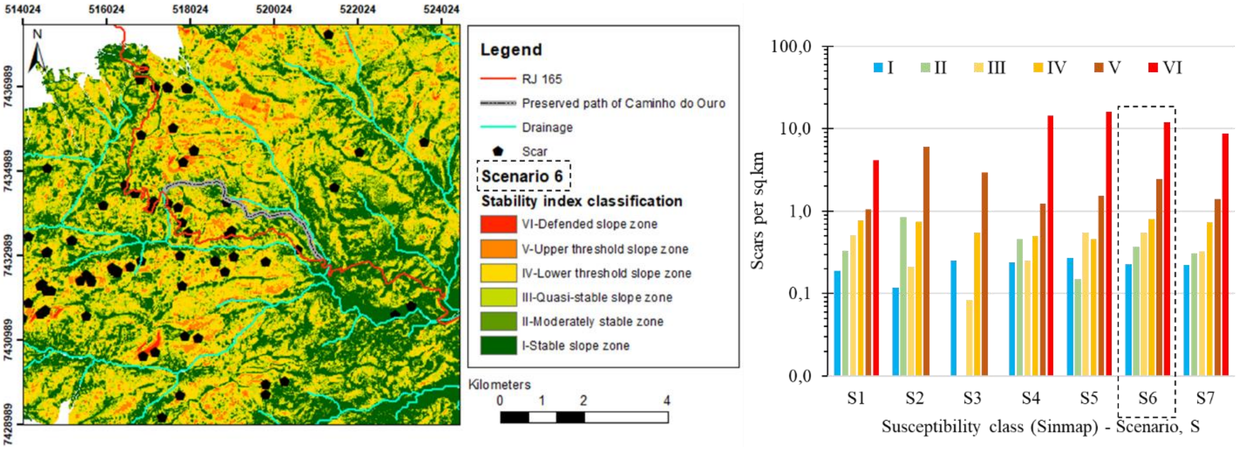


Figure 6. Susceptibility map of SINMAP (scenario 6) (1:90,000), and the histograms showing the scars per square kilometer for all scenarios (S1-S7).

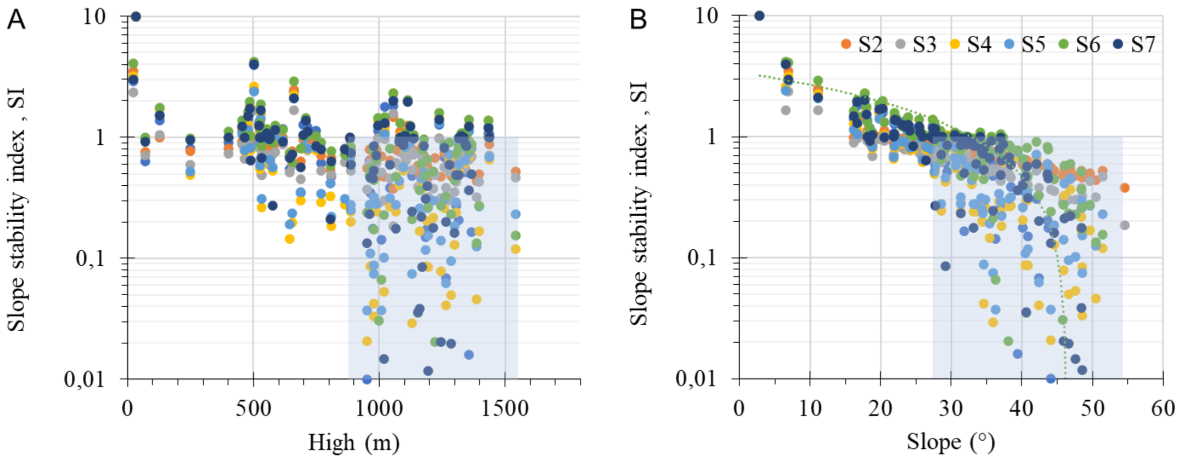


Figure 7. Relationships between the slope stability index (SI) with (A) high and (B) slope angle for the scenarios, S2-S7.

Comparing the histograms and the number of susceptibility classes of each method (CPRM and SINMAP) some considerations can be raised (Figs. 5 and 6). The number of scars per km^2 in SINMAP models can reach values from six to seventeen times higher than the obtained from CPRM map. Generally, the six class divisions proposed by SINMAP index better indicate the landslides occurrence of the last 10 years. However, misleading situations can be reached by the physically-based landslide susceptibility model if success and error indexes are not applied.

Different from Sorbino et al. (2010) as well as Michel et al. (2014) success and errors indexes results, herein the SSi and RRi are normalized by scars per square kilometer and represent together 100%. In this sense, the susceptibility map produced by CPRM has a success index (SSi) around 86% (therefore, 14% of error - RRi), reasonable values for comparative purposes with the physically landslide-based susceptibility models. The SINMAP model achieved values around 91% of success index for the S2 scenario, followed by values around 87% and 86% for S6 and S3 scenarios, respectively. Nevertheless, the scenarios S4, S5 and S7 reached success and errors indexes values under the expectation, an indication of a poor physically landslide model (Fig. 8). Table 3 gathered some results.

It´s important to emphasis, the hydrological and soil parameters used herein in the scenarios S2, S3 and S4 (Table 2) were the same values of scenarios, 1, 2 and 3, respectively, from Nery and Vieira (2015). However, these authors didn´t define clearly among the scenarios what would be a more sensible bunch of input parameters for the model's reproducibility in Serra do Mar. In this sense, the SSi and RRi indexes suggest a good model for scenarios 1 and 2 (herein S2 and S3) and a poor model for scenario 3 (herein S4) with more than 16% of error (Fig. 8 and Table 3). These differences behaviors were roughly pointed out by histogram analysis in Figure 6 of Nery and Vieira (2015), a swallow landslide study in the city of Cubatão (SP) - Serra do Mar domain.

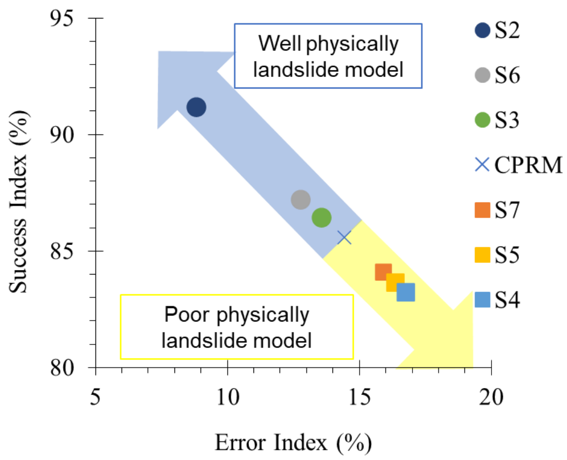


Table 3 - Some results obtained with modified success and error indexes

Method	Assumed condition	N° Scars	Sq. km	Succes (SSi) and error (RRi) indexes	
CPRM	Stable	18	87.2	RRi	14.4
	Unstable	80	65.5	SSi	85.6
Scenario S2	Stable	10	150.9	RRi	8.8
	Unstable	88	1.7	SSi	91.2

Figure 8. The success and error indexes for SINMAP and CPRM susceptibility maps.

6. CONCLUSION

Gravitational movements affecting civilians and tourists along the RJ-165 -- an archaic highway to the dynamic of the Serra do Mar -- is a reality for the Paraty city, as the event experienced on 05/16/2019. The titling of UNESCO world heritage will bring a large number of tourists, and economic growth is expected for the municipality of Paraty, whose history and landscape is unique in the world. Fitting the civil authorities with the responsibility of conducting actions to ensure traffic and sustainable growth for the next few years. This project serves the region with an updated landslide susceptibility map that can be used by the authorities and avoid life loss.

The Geological Survey of Brazil map indicates portions with high susceptibility to shallow landslides along RJ 165, as well as the maps developed by the physically-based landslide susceptibility model, SINMAP. For the second method, a notable increase is observed in the number of landslide scars per square kilometer in all the scenarios, due to the restriction of the high susceptibility classes areas. However, it is essential to check the parameterization through success and error indexes once it can produce errors higher than the Geological Survey of Brazil map, used here as a comparative basis – a standard.

When the geotechnical and hydrological characteristics parameters are representative of the study site, physically-based landslide susceptibility models can generate success rates significantly higher than the standard qualitative maps. SINMAP manages to be much more precise and accurate in the spatial definition of back-analysis of shallow landslides in the RJ-165 region over the last 10 years.

References

Amaral Junior, A. F. D. (2007). Mapeamento geotécnico aplicado a análise de processos de movimentos de massa gravitacionais: Costa Verde-RJ-escala 1: 10.000 (Doctoral dissertation, Universidade de São Paulo).

Bitar, O. Y. (Org) (2014). Cartas de suscetibilidade a movimentos gravitacionais de massa e inundações-1: 25.000: nota técnica explicativa. IPT/CPRM.

Brasil, 2012 - http://www.planalto.gov.br/ccivil_03/_ato2011-2014/2012/lei/l12608.htm

Calvello, M., d'Orsi, R. N., Piciullo, L., Paes, N., Magalhaes, M., & Lacerda, W. A. (2015). The Rio de Janeiro early warning system for rainfall-induced landslides: analysis of performance for the years 2010–2013. International journal of disaster risk reduction, 12, 3-15.

Cerri, R. I., Rosolen, V., Reis, F. A., Filho, A. J. P., Vemado, F., do Carmo Giordano, L., & Gabelini, B. M. (2020). The assessment of soil chemical, physical, and structural properties as landslide predisposing factors in the Serra do Mar mountain range (Caraguatatuba, Brazil). Bulletin of Engineering Geology and the Environment, 1-14.

CPRM (2015). Carta de suscetibilidade a movimentos gravitacionais de massa e inundações: município de. Paraty, RJ. CPRM – Serviço Geológico do Brasil, 2015.

CPRM (2020) - https://www.cprm.gov.br/publique/Noticias/CPRM-publica-nova-Carta-de-Suscetibilidade-e-amplia-cobertura-para-96%25-do-Rio-de-Janeiro-6205.html

Gutiérrez-Martín, A. (2020). A GIS-physically-based emergency methodology for predicting rainfall-induced shallow landslide zonation. Geomorphology, 107121.

Lan, H. X., Zhou, C. H., Wang, L. J., Zhang, H. Y., & Li, R. H. (2004). Landslide hazard spatial analysis and prediction using GIS in the Xiaojiang watershed, Yunnan, China. Engineering geology, 76(1-2), 109-128.

Meisina, C., & Scarabelli, S. (2007). A comparative analysis of terrain stability models for predicting shallow landslides in colluvial soils. Geomorphology, 87(3), 207-223.

Michel, G.P., Kobiyama, M. & Goerl, R.F. (2014). Comparative analysis of SHALSTAB and SINMAP for landslide susceptibility mapping in the Cunha River basin, southern Brazil. J Soils Sediments 14, 1266–1277.

Nery, T. D., & Vieira, B. C. (2015). Susceptibility to shallow landslides in a drainage basin in the Serra do Mar, São Paulo, Brazil, predicted using the SINMAP mathematical model. Bulletin of Engineering Geology and the Environment, 74(2), 369-378.

Pack RT, Tarboton DG, Goodwin CN, Prasad A (2005) SINMAP 2- A stability index approach to terrain stability mapping. Utah State University. http://hydrology.usu.edu/sinmap2/. Accessed March 2020.

Portal G1. (2019) https://g1.globo.com/sp/vale-do-paraiba-regiao/noticia/2019/05/16/tamoios-e-interditada-por-risco-de-deslizamento-na-serra.ghtml

Ribas, M. C. (2003). História do Caminho de Ouro em Paraty.

Santos, Á. R. (2004). A grande barreira da Serra do Mar: da trilha dos Tupiniquins à Rodovia dos Imigrantes. O Nome da Rosa.

Silva, O. C. A. (2010). Análise da suscetibilidade a escorregamentos e as implicações da evolução do uso e cobertura do solo no município de Paraty, RJ (Doctoral dissertation, Universidade de São Paulo).

Sorbino, G., Sica, C., & Cascini, L. (2010). Susceptibility analysis of shallow landslides source areas using physically based models. Natural hazards, 53(2), 313-332.

Tatizana, C., Ogura, A. T., Cerri, L. D. S., & Rocha, M. D. (1987a). Análise de correlação entre chuvas e escorregamentos-Serra do Mar, município de Cubatão. In Congresso Brasileiro de Geologia de Engenharia (Vol. 5, No. 1987, pp. 225-236).

Tatizana, C., Ogura, A. T., Cerri, L. E., & Rocha, M. D. (1987b). Modelamento numérico da análise de correlação entre chuvas e escorregamentos aplicado às encostas da Serra do Mar no município de Cubatão. In Congresso Brasileiro de Geologia de Engenharia (Vol. 5, No. 1987, pp. 237-248).

Tupinambá, M., Monlevade, A. A., Brito, J. V., Waldherr, F. R., & Tupinambá, A. (2014). Proveniência do material rochoso utilizado no calçamento do caminho velho da estrada real entre Parati (RJ) e Cunha (SP). Geonomos.

Unesco, 2019 - https://whc.unesco.org/en/list/1308/

Vieira, B. C., Fernandes, N. F., Augusto Filho, O., Martins, T. D., & Montgomery, D. R. (2018). Assessing shallow landslide hazards using the TRIGRS and SHALSTAB models, Serra do Mar, Brazil. Environmental earth sciences, 77(6), 260.