Proceedings of the 20th International Conference on Soil Mechanics and Geotechnical Engineering– Rahman and Jaksa (Eds)

Evaluation of geological-geotechnical hazard associated with the triggering of landslides in the urban area of Além Paraíba – Minas Gerais, Brazil

Évaluation des risques géologiques et géotechniques associés au déclenchement de glissements de terrain dans la zone urbaine d'Além Paraíba – Minas Gerais, Brésil

Eduardo Marques, Laís Assis, Leonardo Souza & Leandro Roque
Department of Civil Engineering, Federal University of Viçosa, Brazil, emarques@ufv.br

Cleverson Lima
Engineering and Technological Departament, Santa Cruz State University, Brazil

ABSTRACT: The hazard scenarios for landslides in Brazilian municipalities are marked, mainly, by anthropogenic changes in slopes, where the index of housing and precarious settlements, associated with geological and physiographic aspects, systematically intensifies the development of landslides. Studying causes and effects, as well as ways to stabilize or avoid deflagration are methods to contribute to minimizing hazard and possible associated losses. In this sense, this article presents the methodology Ministry of Cities identification with the support of obtaining high resolution aerial photos, in scale of detail, the results obtained from a geological-geotechnical mapping related to the hazard of landslides in the urban area of the city of Além Paraíba -MG, Brazil. The mapping of hazard of landslides enabled 104 sectors to be identified, registered and georeferenced in a GIS environment. Using the methodology of the Ministry of Cities proved to be efficient for identifying hazard, although it is qualitative, made through field observations and dependent on specialized technical staff to carry out the diagnoses. The identified hazard areas are mostly installed on steep slope > 30º, present cuts installed without a geotechnical approach, with proximity of dwellings to the base and/or top of slopes, inappropriate landfills, lack of and/or inefficiency of rainfall drainage, and inadequate waste disposal. In areas of high and very high hazard, features of instability were clearly observable. In addition, natural geoenvironmental susceptibility should also be emphasized, as it is located in a region of geological fault zone, which may increase the probability of triggering during rainy periods.

RÉSUMÉ: Les scénarios d'aléa pour les glissements de terrain dans les municipalités brésiliennes sont marqués, principalement, par des changements anthropiques dans les pentes, où l'indice d'habitat précaire, associé aux aspects géologiques et physiographiques, intensifie systématiquement le développement des glissements de terrain. L'étude des causes et des effets, ainsi que les moyens de stabiliser ou d'éviter la déflagration sont des méthodes pour contribuer à minimiser les risques et les pertes éventuelles associées. En ce sens, cet article présente la méthodologie d'identification du Ministério das Cidades avec l'appui de l'obtention de photos aériennes à haute résolution, à l'échelle de détail, les résultats obtenus à partir d'une cartographie géologique-géotechnique liée à l'aléa de glissements de terrain dans la zone urbaine de la ville. d'Além Paraíba -MG, Brésil. La cartographie de l'aléa de glissements de terrain a permis d'identifier, d'enregistrer et de géoréférencé 104 secteurs dans un environnement SIG. L'utilisation de la méthodologie du Ministère des Villes s'est avérée efficace pour identifier l'aléa, bien qu'elle soit qualitative, réalisée à partir d'observations de terrain et dépendant d'un personnel technique spécialisé pour réaliser les diagnostics. Les zones à risques identifiées sont pour la plupart installées sur des pentes raides > 30º, présentent des coupes installées sans approche géotechnique, avec proximité des habitations au pied et/ou au sommet des pentes, décharges inappropriées, manque et/ou inefficacité du drainage des pluies, et traitement des déchets. Dans les zones à risque élevé et très élevé, des caractéristiques d'instabilité étaient clairement observables. De plus, la susceptibilité géoenvironnementale naturelle doit également être soulignée, car elle est située da

KEYWORDS: Landslide, hazard assessment; geotechnical cartography, unmanned aerial vehicle

1 INTRODUCTION.

In Brazil, the population occupying hillsides is increasing. This fact, together with lack of urban planning and the inefficiency of public housing policies, has led to an increase in accidents related to landslides in occupied areas.

Calderón and Segura (1996); Carriço (2002); Souza (2014) emphasize that, in the urbanization process, anthropic intervention, whether due to the unsuitability or geotechnical inaptitude of the areas occupied for urban land use, is commonly the main cause of immediate or medium-term problems. The culture of precaution and disaster prevention actions in Brazil is considered highly fragile (Alheiros, 2011, Toro & Pedroso, 2013). According to Medd & Marvin (2005: p.44), in most cases, emergency policies are highlighted in order to demonstrate that something is being done, neglecting prevention work.

A well-known fact of this approach was on the agenda of the United Nations General Assembly on Disaster Risk Reduction, held in York (UK) in September 2011. Based on this approach, the report of the Brazilian Federal Accounting Court - TCU (TC 000.741/2011-6) has highlighted that for every dollar invested in prevention can save many dollars in post-disaster reconstruction. Given this information, the Brazilian Ministry of National Integration estimated that for each R$ 1.00 spent on prevention, R$ 7.00 is saved on reconstruction (Coutinho, 2014).

From the above, it can be concluded that socio-natural hazard management is increasingly essential for social and economic development in Brazilian municipalities, since investment and amounts spent post-disaster are much greater than those committed in executing preventive measures. According to Tominaga (2015), considering all phenomena involving disasters, landslides have been responsible for the highest number of fatalities and significant economic losses in Brazil.

Occupying hillside regions is always subject to landslides, especially in the case of precarious settlements, built without engineering parameters and unmonitored, commonly, by specialized technical guidance or prior authorizations for construction from the municipality. In order to assess the degree of hazard to which these dwellings are subject, it is necessary to perform geological-geotechnical mapping. Studying causes and effects, as well as ways to stabilize or prevent these processes, can contribute to minimize disasters and possible associated losses.

In this context, geological and geotechnical mapping and qualitative delineation of the main hazard sectors in an urban area were carried out in order to determine the degree of hazard of landslides in the municipality of Além Paraíba, Minas Gerais state. At a later stage, the results of which will not be presented in this article, three areas of high and very high hazard were selected and a detailed geological-geotechnical characterization and a quantitative hazard analysis was carried out there, comprising stability analyses of certain slopes and the possible extent of the mobilized masses.

2 METHODS AND MATERIALS APPLIED

2.1 *Study location*

The municipality of Além Paraíba is located in the southeastern part of the state of Minas Gerais, on the border with Rio de Janeiro state – southeast Brazil, with a territorial extension of 510,250 km² and an estimated population of 35.362 inhabitants (IBGE, 2019). The altimetric dimensions of the area vary between 100 and 1019 meters (Figure 1).

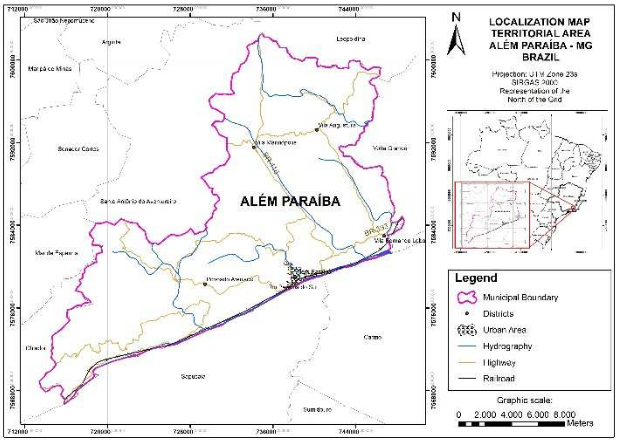

Figure 1. Study Location

2.2 *Geological and Geomorphological Aspects*

The area in question is part of the Minas Gerais Zona da Mata, a micro region of Cataguases region, and corresponds to a segment of geological formation which is mostly part of the Cristalino complex, composed of gneisses and migmatites, with a varying degree of metamorphism. The metasediments (quartzites and mica schists) are less widespread. The most recent sedimentary formations are dated to the Tertiary and Quaternary, and occur along the valleys and waterways and larger beds, made up of gravel, sand, sites and clay (Brasil, 1970; Baruqui, 1982; Brasil, 1983).

The geological features of Além Paraíba are composed of five units, as shown in the geological map of the municipality. This information was extracted from the regional cartographic base (SF 23 - Rio de Janeiro, scale 1: 1,000,000) and South of Minas (Scale 1: 100,000) and confirmed by field observation.

Geologically, the analyzed urban area is predominantly located in the Juiz de Fora Complex, which represents the base of the Paraíba do Sul sedimentary basins. These lands have a high degree of metamorphism and intense compressive and transcurrent tectonics, in which there are occurrences of striking planes of discontinuities resulting from faults and shear zones, which consequently increase susceptibility to landslides.

The study area has rugged topography, with a predominance of strong mountainous relief. The hills show alignment of ridges related to a stretch of the Paraíba do Sul River valley, presenting a bundle of geological faults preferentially oriented NE-SW.

Corrêa Neto *et al.,* (1993), point out that the Shear Zone of the Paraíba do Sul River is part of a fault system that groups from the Lancinha fault in Paraná state to the Cubatão fault, in São Paulo state, deflecting towards the north, continuing in the Guaçuí Lineament, in Espírito Santo state.

According to Fernandes and Amaral (2003), geological faults have a strong influence on the conditioning of landslides. The joints encourage the weathering process and, when silicified, generate a barrier to water flow by waterproofing the fault plane.

The soils in Além Paraíba show aspects according to the variation of the geological framework of the region. In general, the predominant soils are mature and residual young clay-sandy to sandy-silty soils, and colluvium soils. Rocky materials are also observed, deposits of talus at the foot of the slopes and boulders and alluvial soils in the riverbed.

According to Moreira and Camelier (1977), the predominant geomorphological unit of the Zona da Mata region is the morphostructural domain of the Lowered Crystalline Plains. The surfaces of concave-looking rounded hills have stretches of alluvial plains, highlighting the greater relevance of the plains associated with the Paraíba do Sul River and the Limoeiro Stream.

These geological and geomorphological conditions, associated with soil use, vegetation cover and intense and/or concentrated rainfall, principally in the summer, heighten the occurrence of landslides.

According to the Köppen classification, the climate in the municipality is of the Aw type, that is, tropical climate with dry winter. Average annual rainfall is 1303 mm with average temperature 23.2 ºC (Antunes, 1986).

The Municipality of Além Paraíba has a history of landslides and floods, mainly between november and march, a period with high rainfall. The month of January of the year 2012 stand out from the record, when several events affected practically the whole municipality, leaving the city paralyzed for some four months.

2.3 *Updating the Cartographic Base - Obtaining images by UAV and Digital data processing*

Aiming to update the digital cartographic document base for the study area in scale of detail, (1:2.000), compatible with the reality of the urban area, an Unmanned Aerial Vehicle - UAV model BATMAP II was used to take up-to-date aerial images. In the UAV, the flight plans were defined so as to obtain aerial photos of the entire area to be mapped. To create the database collected from the flights and add the aerial photos, the geographic coordinates in the UTM Projection zone 23S - SIRGAS 2000 were georeferenced and associated.

The image processing and the modeling were done at the Department of Civil Engineering of Universidade Federal de Viçosa, using the Agisoft PhotoScan computer program, used to generate point clouds, a 3D Models and orthomosaics (Figure 2) and Digital Elevation Model (DEM) (Figure 3). All the products derived from the aerial survey with the UAV were organized based on an orthomosaic. With the geospatial data processed, it was possible to generate a Ground Sampling Distance (GSD) of 9.75 cm/pixel of spatial resolution for the imaged area, which enabled the digital cartographic base to be updated for the purposes of the study. ArcGis® 10.3.1 was used to create thematic maps.

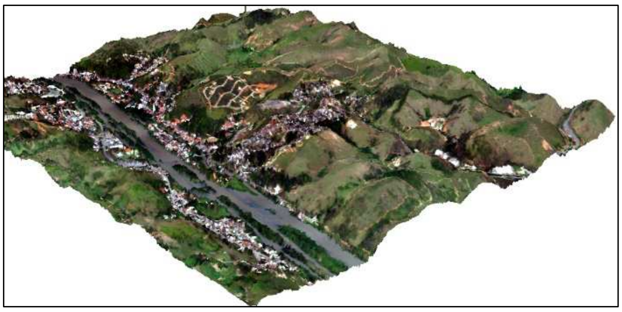

Figure 2. Examples of the 3D Models created from the products obtained from FLIGHT 1.

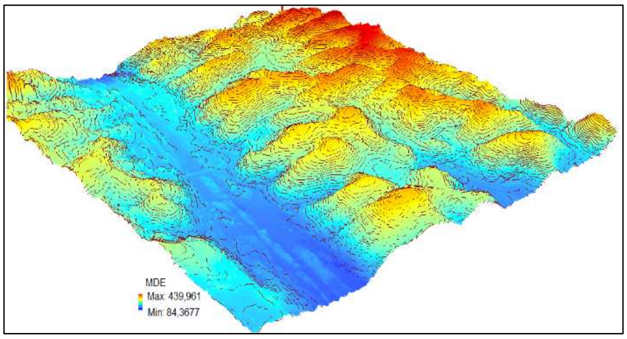

Figure 3. Digital Elevation Model 3D flight 1.

2.4 *Geological-geotechnical hazard mapping to landslides*

The methodology proposed by the Ministry of Cities (Brasil, 2007) was adopted to identify the processes of instability and to put the geological-geotechnical hazard into sectors. At the stage of identifying and mapping hazard, it was first necessary to perform a preliminary recognition of the physical environment of the urban area, through surveys at certain points previously chosen in a regular net, compatible with the work scale, to verify the typologies of geodynamic processes and analyze the conditioning factors triggering agents and movement indicators to be observed during field activity / mapping, such as: a) Factors determining geological hazard: Geology: Lithotype; Change profile; Presence of surface formations; Presence of planar / discontinuity structures; Permeability of material; Declivity: Height of cut / slope; Distances from base and crest of the slope; Height x spacing ratio; Relief: Shape and extent of the slope; Cross-sectional profile of the talweg; Position of the area on the profile of the slope; Position of the dwelling in relation to the watercourse (distance and form of meanders); Scheme for the flow of the watercourse and position in the river basin; Vegetation: Presence of vegetation; Size (trees or undergrowth, for example); Extent of plant cover; b) "Anthropogenic formations": Existence and density of landfills / dumps; Existence and density of garbage; Extent of layers; c) Potentiating Agents: Wastewater / sewage; Septic tanks; Broken Pipes; Leaks; Cuts; Dumps; Garbage / debris; d) Indicators of Movement: Cracks in the ground; Cracks in the dwelling; Land slip; Scars from landslides; Sinkholes; Leaning posts, trees and fences; Deformed structures (bulging or fallen walls); Elevation of water level and turbidity in the event of flooding.

Subsequently, the Civil Defense was requested to supply information from records of landslides already occurred in the municipality. The main points/areas of geological hazard were analyzed, and preliminary vulnerability analysis conducted of the precarious urban settlements and other affected areas to be mapped. Consequently, the geological-geotechnical survey began to divide the area into sectors by means of a register with the help of a checklist including the typology of the processes, scope and materials subject to mobilization, as well as the vulnerability of the elements exposed. The degree of hazard was hierarchized based on the judgment and experience of the technical team (qualitatively), responsible for the survey. The criteria described in Table 1 were used, enabling the hazard sectors to be defined by means of polygons on the cartographic base obtained through the aerial photogrammetric survey with the UAV, which were later transported to the digital database in ArcGis®.

Thus, it was possible to define the degree of occurrence of destructive processes, following the hierarchical criteria shown in Table 1, the hazard areas were qualitatively delineated and the number of dwellings in each delimited sector was calculated.

Table 1. Criteria for the hierarchy of degree of hazard based on the Ministry of Cities methodology (Brasil, 2007).

Likelihood	Description
H1 Low Hazard	1. The predisposing geological-geotechnical conditions (slope, type of terrain, etc.) and the level of intervention in the sector are of no potential for the development of landslides and slippage. 2. No sign/feature/evidence of instability. No indication of development of slope or drainage margin instability. 3. If existing conditions are maintained destructive events are not expected to occur in the period comprised by a normal rainy season.
H2 Medium Hazard	1. The predisposing geological-geotechnical conditions (slope, type of terrain, etc.) and the level of intervention in the sector are of low potential for the development of landslides and slippage. 2. There are some signs/features/evidence of instability (slopes and drainage margins), albeit incipient. Process of instability at an early stage of development 3. If existing conditions are maintained, the possibility of destructive events occurring during episodes of intense and prolonged rains in the period comprised by a rainy season is reduced.
H3 High Hazard	1. The predisposing geological-geotechnical conditions (slope, type of terrain, etc.) and the level of intervention in the sector are of medium potential for the development of landslides and slippage. 2. There are significant signs/features/evidence of instability (cracks in the ground, land slip on slopes, etc.) Process of instability in full development, it still being possible to monitor the evolution of the process. 3. If existing conditions are maintained, the occurrence of destructive events during episodes of intense and prolonged rains in the period comprised by a rainy season is quite possible.
H4 Very High	1. The predisposing geological-geotechnical conditions (slope, type of terrain, etc.) and the level of intervention in the sector are of high potential for the development of landslides and slippage. 2. The signs/features/evidence of instability (cracks in the ground, land slip on slopes, cracks in dwellings or containment walls, leaning trees and posts, scars from landslides, erosive features, proximity of dwelling to banks of stream, etc.) are notable and present

in great number or scale. Process of instabil ity in advances stage of development.
3. If existing conditions are maintained, the occurrence of destructive events during epis odes of intense and prolonged rains in the p eriod comprised by a rainy season is very li kely.

3 RESULTS AND DISCUSSION

The methodology described in the previous section aimed to identify the most common mass movement processes in the urban area of Além Paraíba, to define the degrees of qualitative hazard based on a field survey and to rank existing hazard sectors, according to the criteria related to geological conditions and evidence of instability defined by the Ministry of Cities. Finally. Based on this, for sectors of high and very high degree of qualitative hazard, interventions (engineering works) were proposed that could mitigate the hazard identified in which 104 sectors at hazard of landslides in the study area were hierarchized.

To illustrate, Figure 4 is an extract of the geological-geotechnical hazard sectorization on a scale of detail (1:2000) is presented on the updated digital cartographic base, obtained through aerial surveying with the UAV. The aerial survey covered a total area of 59.8 km².

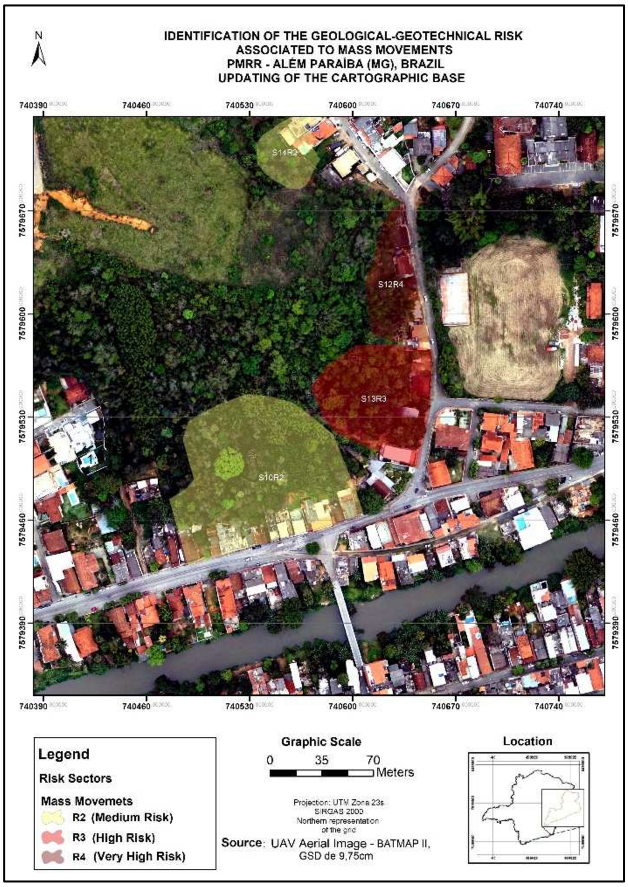

Figure 4. Example of geological-geotechnical hazard identification associated with landslides in the urban area of Além Paraíba (MG).

The growth of disorganized occupation in unstable areas in the municipality is systematically related to the lack of territorial planning and low aptitude for urbanization, besides the natural predisposition of the environment to landslides. As a result, 7 sectors were classified as at very high hazard (H4) of landslides. There were 61 High Hazard sectors (H3) and 36 sectors classified as medium hazard (H2). In the various defined hazard sectors, 720 buildings were identified as at hazard of mass movement, of which 468 are in situations of high or very high hazard.

The main observed characteristics of the identified hazard areas relate to vertical cuts and unsuitable landfills with slope inclination upstream of the elevated households. The surface drainage systems are mostly non-existent on the slopes and deficient in access, and releases and concentrations of wastewater and rainfall were also observed, which consequently contribute to saturation and collapse of the soil. In several sectors, there is garbage and debris along the slope, which alters the equilibrium conditions. In the most critical situations identified there are scars of landslides with land slip delineating surfaces of rupture, with the capacity to mobilize significant volumes of material.

Regarding the natural predispositions observed in the study area, the transition zones with soil-rock contacts and their respective permeability differences stand out. In general, soils in areas with greater slope are not very thick, and in addition to stretches with concentrations of superficial flows, are determinant of instability.

4 CONCLUSIONS

The mapping of hazard of landslides enabled 104 sectors to be identified, registered and georeferenced in a GIS environment. Using the methodology of the Ministry of Cities proved to be efficient for identifying hazard, although it is qualitative, made through field observations and dependent on specialized technical staff to carry out the diagnoses.

Regarding the determinants of these processes, research shows that most of the hazard scenarios are intrinsically linked to the action of man through impacts associated with disorderly occupation and settlements in precarious conditions on the slopes of the municipality, which has increased the number of areas at hazard of landslides.

In addition to these aspects, these areas are mostly installed on steep slope > 30º, present cuts installed without a geotechnical approach, with proximity of dwellings to the base and/or top of slopes, inappropriate landfills, lack of and/or inefficiency of rainfall drainage, and inadequate waste disposal. In areas of high and very high hazard, features of instability were clearly observable. Natural geoenvironmental susceptibility should also be emphasized, as it is located in a region of geological fault zone, which may increase the probability of triggering during rainy periods.

It is important to emphasize that relativization of hazards must be understood by municipal public management and the population in general. The municipal management, considering its administrative structure, should draw up norms and procedures to establish technical quality, standardization and specialization of the civil protection and defense activities. The population, however, must feel responsible for the conservation, re-qualification and creation of the public space, acting in the formulation of policies together with the administrative sphere so that it can solve and/or minimize the problems encountered.

5 ACKNOWLEDGEMENTS

This study was financed in part by the Coordenação de A perfeiçoamento de Pessoal de Nível Superior - Brasil (CA PES) - Finance Code 001.

6 REFERENCES

ALHEIROS, M.M. Gestão de Riscos Geológicos no Brasil. São Paulo: ABGE. Revista Brasileira de Geologia de Engenharia e Ambiental - REGEA, v.1, n.1, p. 109 – 122, nov2011.

BARUQUI, F. M. Inter-relações solo-pastagens nas regiões Mata e Rio Doce do estado Minas Gerais. (Dissertação de Mestrado) Solos e Nutrição de Plantas, 1982. Viçosa: UFV, 1982. 119p.

BRASIL. Ministério da Agricultura. Levantamento Exploratório dos Solos da região sob influência da CIA. Vale do Rio Doce. Boletim Técnico n 13. Rio de Janeiro, 1970. 154p.

BRASIL. Ministério das Minas e Energia. Secretária-Geral. Projeto RADAMBRASIL: levantamento de recursos naturais. Folhas SF. 23/24. Rio de Janeiro/Vitória. Geologia. Rio de Janeiro, v. 32. 1983. 775p.

BRASIL. Ministério das Cidades. Mapeamento de Risco em Encostas e Margens de Rios. CARVALHO, C.S.; MACEDO, E.S; OGURA, A. T.; (orgs). Brasília, Instituto de Pesquisa Tecnológicas, 2007. Disponível em: <http://www.cidades.gov.br/>. Acesso em: 05 de maio, 2019.

CALDERÓN, A.I. e SEGURA, D.S.B. Riscos sócio-ambientais: a complexidade do caso paulistano. Debates sócio-ambientais. CEDEC, São Paulo, n.4, p.3-5, 1996.

CARRIÇO, J.M. Legislação urbanística e segregação espacial nos municípios centrais da Região Metropolitana da Baixada Santista. 2002. 234f. + anexos. (Mestrado em Estruturas Ambientais Urbanas) – Faculdade de Arquitetura e Urbanismo da Universidade de São Paulo, São Paulo.

CORRÊA NETO A.V., DAYAN H., VALENÇA J.G., RAFAEL CABRAL A. 1993. Geologia e estrutura da zona de cisalhamento do rio Paraíba do Sul entre Três Rios, RJ e Sapucaia, RJ. In: SBG, Simp. Geol. Sudeste, 3, Atas, p. 194-200.

COUTINHO, N. C. A. Proteção Constitucional em Face de Desastres Hidrológicos. Revista dos tribunais online. Acesso em dez. 2018. Available at http://www.ceaf.mppr.mp.br/arquivos/File/Biblioteca/0520_3_Encontro_Anual_da_Rede_Ambiental/RTDoc16_5_11_2_9_PM.pdf

FERNANDES, N. F; AMARAL, C. P. 2003. Movimentos de Massa: Uma Abordagem Geológico- Geomorfológico. In: GUERRA, A. J. T; CUNHA, S. B. (orgs). Geomorfologia e Meio ambientes. Editora Bertrand Brasil. Rio de Janeiro Cap.3, p 123-194.

MEDD, W.; MARVIN, S. (2005). From the politics of urgency to the governance of preparedness: a research agenda on urban vulnerability. Journal of Contingencies and Crisis Management, v.13, n.2, pp. 44-49.

MOREIRA, A.A.N. & CAMELIER, C. 1977. Relevo. In: Fundação Instituto Brasileiro de Geografia e Estatística, Rio de Janeiro. Vol. 3. Pp. 1-150.

TOMINAGA, L. K., SANTORO, J., AMARAL, R. do. Desastres naturais: conhecer para prevenir / 3ª ed.- São Paulo: Instituto Geológico, 2015.

TORO, J.; PEDROSO, F.F. (ed.) Gestão de Riscos de Desastres no Brasil: panorama atual e estratégias futuras. International Bank for Reconstruction and Development/ The World Bank; GFDR – Global Facility for Disasters Reduction and Recovery, 2013. 60p.