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Geotechnical modeling on susceptible landslides initiation zones in Três Rios-RJ (Brazil) city

Modélisation géotechnique sur les zones d'initiation de glissements de terrain sensibles dans la ville de Três Rios-RJ (Brésil)

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ABSTRACT: Urbanization combined with high population density characterize current settlements in Brazilian cities, being an important social, economic and environmental phenomenon, which compromises the urban space planning and management. Therefore, the socioenvironmental risks perception, especially geological-geotechnical ones, becomes relevant, and must integrate structural actions and modern urban planning. This study aims to propose an information base modeling for a landslides susceptibility study in Tres Rios-RJ-Brazil city due to the land use irregular occupation. For this purpose, a LiDAR database associated with soil and rain parameters, applied to TauDEM-SinMAP model, will be used to obtain the most likely areas for the mass movement initiation (MLIP). This model points out the MLIPs based on a geotechnical, topographic and hydrological soils assessment in the interest region, providing a final indicative map with greater susceptibility areas to landslide. The product resulting from this research seeks to show that anticipated geological-geotechnical planning for cities helps in the prevention of urban socio-environmental disasters.

RÉSUMÉ: L'urbanisation combinée à une forte densité de population caractérisent les implantations actuelles dans les villes brésiliennes, étant un phénomène social, économique et environnemental important, qui compromet la planification et la gestion de l'espace urbain. Dès lors, la perception des risques socio-environnementaux, notamment géologiques-géotechniques, devient pertinente, et doit intégrer actions structurantes et urbanisme moderne. Cette étude vise à proposer une modélisation de base d'informations pour une étude de susceptibilité aux glissements de terrain dans la ville de Tres Rios-RJ-Brésil en raison de l'occupation irrégulière de l'utilisation des terres. A cet effet, une base de données LiDAR associée aux paramètres du sol et de la pluie, appliquée au modèle TauDEM-SinMAP, sera utilisée pour obtenir les zones les plus probables pour l'initiation du mouvement de masse (MLIP). Ce modèle indique les MLIP sur la base d'une évaluation géotechnique, topographique et hydrologique des sols dans la région d'intérêt, fournissant une carte indicative finale avec des zones plus sensibles aux glissements de terrain. Le produit issu de cette recherche vise à montrer que la planification géotechnique et géotechnique anticipée des villes contribue à la prévention des catastrophes socio-environnementales urbaines.

KEYWORDS: Taudem model; Shallow landslides; heavy rainfall; land use

1 INTRODUCTION.

Natural disasters are an increasingly present theme in people's daily lives, regardless of whether they live in risky areas or not. Although at first the term leads us to associate it with earthquakes, tsunamis, volcanic eruptions, cyclones and hurricanes, Natural Disasters also include more localized processes and phenomena such as landslides, floods, subsidence and erosion, which can occur naturally or induced by man (TOMINAGA; SANTORO; AMARAL, 2009).

UN-ISDR (2004) defines disaster as "a serious disturbance in the functioning of a community or society involving large-scale human, material, economic or environmental losses, whose impacts exceed the capacity of the community or society to bear its own resources.

Human actions tend to amplify the severity of natural disasters, producing threats in stable areas where such conditions did not exist. This is due to changes in the area, through civil construction, inadequate handling, environmental disfigurement, without considering the natural dynamic processes. Therefore, the importance of the perception of environmental vulnerability in the face of risk events gives a dimension that must be considered for regional development, strengthening mechanisms for coping with causes and consequences, minimizing economic, social and environmental losses.

Considering the current scenario, public administrators, in possession of decision support tools and reliable data, are obliged to re-plan their responses to future situations of natural hazards, and may continue with a redistribution of vulnerable housing; prevention and mitigation plans as a way to minimize the effects of future events; associated with the strengthening and integration of local and national civil defense systems, sharing means and resources.

This work presents a proposal for hydrogeotechnical modeling, on a municipal scale, at a qualitative level, regarding the susceptibility of mass movements applied to occupied urban areas, considering for this, the scenarios of land use and its diagnosis. This proposal in development, aims to indicate the susceptible areas and later analyze the possible consequences arising from mass movements in a medium-sized city, in frank expansion and industrialization, and how the lack of public urban planning policies that can lead to the emergence of avoidable risk zones.

In this way, the products of this research work aim to contribute to local, integrated and sustainable development for

the city of Três Rios - RJ, this municipality, inserted in the National Plan for the Prevention of Natural Disasters, with the supply of maps, maps and tools for support the decisions of public agents. In other words, they can help and direct the appropriate public policies related to geological-geotechnical risks.

2 METHODS AND MATERIALS APPLIED

2.1 *Study location*

The study will be carried out in the city of Três Rios, which is part of the Paraíba do Sul River Valley, in the Center-South region of the state of Rio de Janeiro, being inserted in the Atlantic Forest biome, characterized by low hills and aligned hills, with unevenness less than 50m (always in the WSW-ENE direction), flanked by higher hills and low hills. These lands located close to the Paraíba do Sul River gutter have, in general, eutrophic Red-Yellow and Red Argisol soils, due to the less humid climate in this zone, with annual totals between 1,100 and 1,300 mm/year.

In Figure 1, it indicates the municipal limits of Três Rios, in the geographical framework of Latitude 22º7'4'12,60 ”S to 22º09'52,87” S and Longitude 43º15'23,33 ”W to 43” 04'43, 97"W.

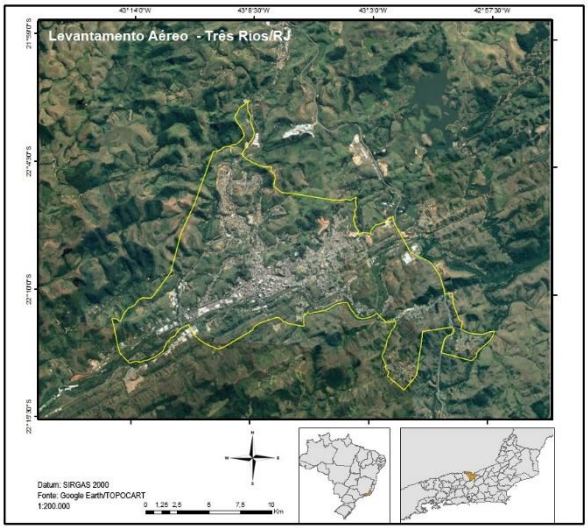


Figure 1. Study Location

2.2 *Digital Elevation Model (DEM)*

The DEM was generated from the cloud of points obtained by laser profiling (LiDAR), which after filtering the disposable points (tree tops, posts, houses, etc.), will remain a database with more than 20 million X coordinates, Y, Z (Latitude, Longitude and Altitude). Laser profiling was processed with a spatial resolution of 10 cm, covering the entire urban area of the city, totaling 35 km². The density of points adopted in the mapping was 2 ppm (points per square meter), with the objective of generating maps on the 1:2000 ladder. The flight plan considered 30% lateral and 60% longitudinal overlaps in order to prevail the required resolution, as can be seen in figures 2 and 3.

The flight was carried out with field support through GNSS receivers, by the aerotriangulation system that met the analytical and semi-analytical requirements.

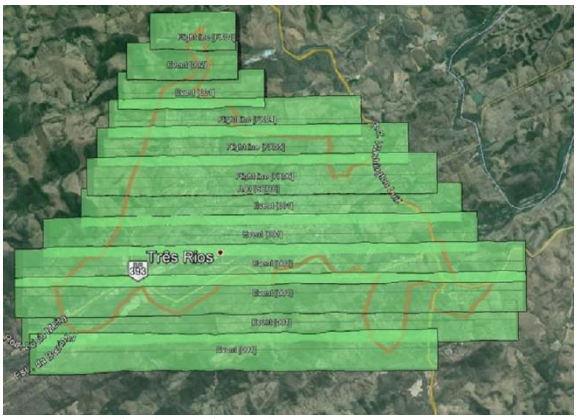


Figure 2. Flight plan with overlays

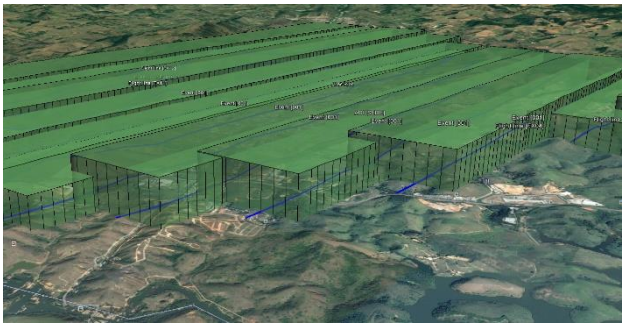


Figure 3. 3D view of the flight plan

2.3. *SPT Survey*

SPT survey reports were obtained from the municipality of the municipality and partner companies in order to prepare a database of subsoil parameters in discrete points in the municipality. These data, after being cataloged, provided information about the type of soil and layer thickness, in addition to the percussion resistance parameters. Such drilling holes contemplate several neighborhoods in the urban area, allowing the formation of a map of soils and subsoils, with their respective mechanical properties arranged at each meter of depth. The spatialization of this substrate information provided the soil resistance parameters through correlations for the urban perimeter. The holes had an average depth of 10.0 m, some of which were executed with the aid of water circulation and protected by a 63.5 mm coating, in addition to sample extraction by a standard 50.8 mm external diameter sampler .

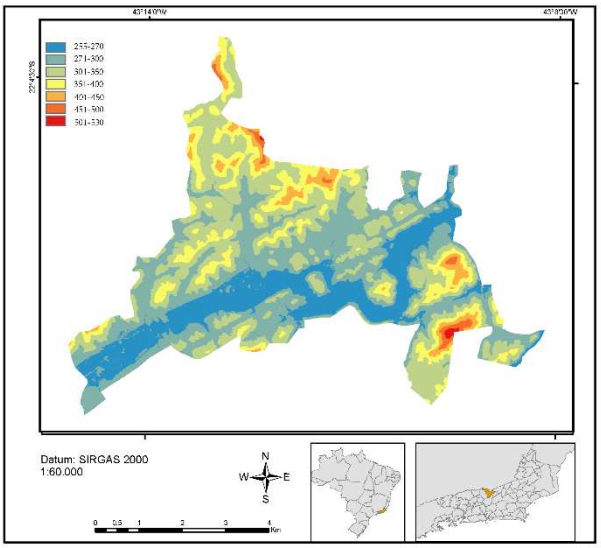
2.4. *Data Processing*

Partnerships were made with various public bodies, at the state and federal level, in order to accumulate the initial basic information for the development of studies. For this, the Civil Defense of the Municipality of Três Rios, Civil Defense of the State of Rio de Janeiro, IBGE (Brazilian Institute of Geography and Statistics), FURNAS Electric Company, Universities and the Municipality of Três Rios, made their databases viable the various information needed for risk modeling at the municipal level, in the case of Três Rios.

From the range of information available, the Laser Profiling (LiDAR) performed in the municipal urban area was adopted in order to classify the type of urban land use and obtain the topographic parameters, obtaining the Digital Elevation (DEM) using ArcGIS 10.3.1 software (Figure 4). Then, a crossing was made with the hydrography, vegetation and points of interest, limiting them to the area in question, using the database provided by IBGE, in a scale of 1:25,000. After this processing, as a new product, a map was obtained indicating the municipal drainage network, which considers the local relief and the different nuances of the occupied areas. As a result of this

analysis, a superficial hydrogeotechnical profile of the area was drawn up, which provided the areas of greatest susceptibility to mass movement.

Figure 4. Digital Elevation Model



With these results in hand, it was possible to characterize the area of greatest risk considering its slope, accumulation of heavy rainfall in the hydrographic basin and possible areas affected by landslides using the TauDEM tool (Terrain Analysis – Digital Elevation Models). This tool allows an integrated analysis of the entire surface and subsurface, unlike other tools found in the market that make specific assessments. These maps will subsidize the government to take measures for prevention, mitigation and urban socio-environmental management.

Thus, the D∞ algorithm was used, present in the TauDEM tool, which disperses the water flow proportionally according to the inclination of the adjacent cell, that is, when compared to other methodologies, this tool distributes the rain flows approximating with the reality found in nature. Its advantage compared to the traditional D8 method is that the discharge flow is not limited to the 8 paths adjacent to the cell and possible flow, increasing the possibility, since the analysis is performed in the cell the cell and the dispersed flow in the same way.

3 RESULTS AND DISCUSSION

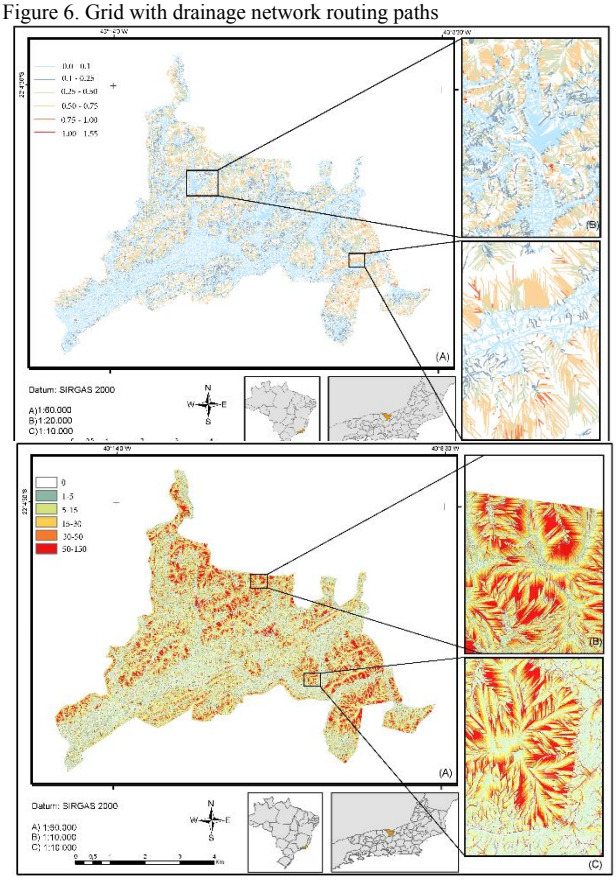
Data processing indicated the points with the highest probability of occurrence of mass movements considering the intensity of rainfall, the surface drainage network and geotechnical parameters.

Starting from the database obtained from the various agencies, we sought to understand the direction of rainwater within the urban context, modeling the surface flow networks and concentration zones of these waters. For this, we used the D∞ algorithm present in the TauDEM tool, which distributed the water flows proportionally according to the inclination of each cell. In Figure 5, the flow direction of the municipal drainage network is presented and, in Figure 6, the paths that each drainage flow takes are presented.

These paths indicate the distance traveled by the water flow and the speed at which this flow reaches its base, given that it is obtained from its inclination. Thus, this information serves as an initial parameter on the potential generator of risk caused by the action of rainwater in an urban environment. In Figure 5, the blue points (lower) of rainwater concentration and the individual drainage paths are perceived, while in Figure 6, it is noticed where points in red such as those that concentrate the highest velocities of runoff of rainwater.

Figure 5. Surface drainage flow vector

Figure 6. Grid with drainage network routing paths



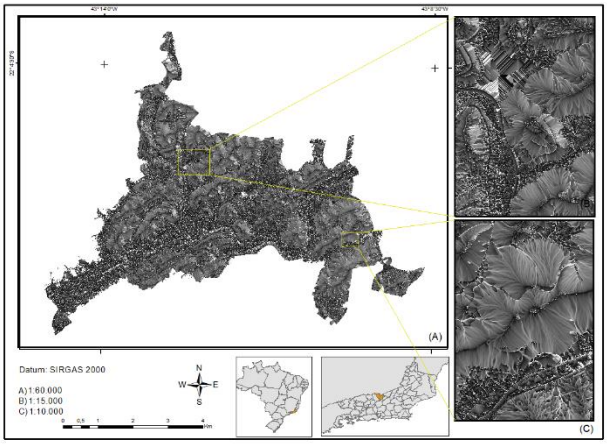
When superimposed on a satellite image (Figure 7), the water concentration points and the post-rain drainage paths are clearly evident. These paths show the influence of relief and water in the sloping areas and potentially at risk, and are easily identified in the grid in red. An observation can be made at the lowest points, where, depending on rainfall, there may be accumulations of water and flooding. This, in fact, has been observed in the last rains recorded in the city, being an indication of an improvement in the rainwater drainage network. Nevertheless, this figure shows the paths that these waters take on steep slopes, already indicated in the slope extraction of the Digital Elevation Model, and anthropically degraded.

Figure 7. Overlapping of Flows and Paths that rainwater travels, considering the local topography in a stretch of the urban area.

Knowing the drainage flow path and associating the geotechnical parameters, estimated from the SPT drilling reports, it is possible to simulate the behavior and spread of water in the subsurface. This algorithm, present in the TauDEM tool, allows us to understand the distribution of water in the subsurface, allowing us to obtain a soil moisture index for a given

precipitation condition. This discussion is interesting, especially on slopes with major interference or within urbanized areas. Figure 8 shows the area of specific contribution of the subsurface, which shows how infiltrated rainwater is spread.

Figure 8. Spreading of rainwater on the subsurface with an estimate of the moisture content in the soil.



It is observed, that the darkest points are the starting points of the slow subsurface flow of the infiltrated waters, showing the cell-to-cell spreading in the soil by the gray scale gradient. This calculation considers the logarithm of the ratio between the distance and its slope. The spreading flow ends up to the veins or blank paths that concentrate the drained water. The importance of this map is given to simulating places that may have an increase or concentration of water, increasing the weight of the massifs, increasing the risk of a failure on slopes.

Finally, it was associated with the geotechnical parameters estimated for the region's soils, such as cohesion and soil friction angle, generating a map illustrated in Figure 9, which indicates the regions with the greatest potential for landslides, providing initial information for the teams defense officers carry out an on-site verification of its fragility.

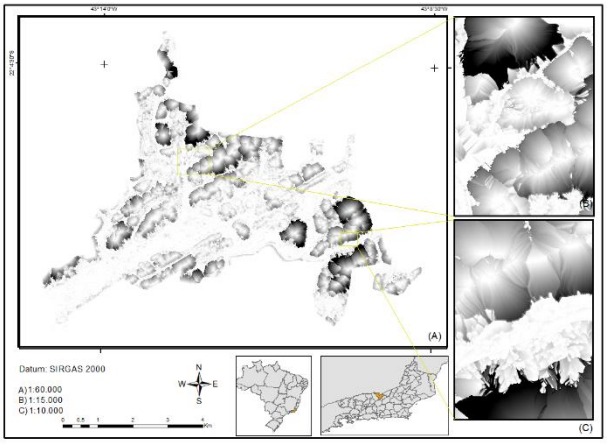


Figure 9. Vulnerable areas, according to topographic, geotechnical and hydrological criteria

4 CONCLUSIONS

The importance of a study, with the association of diverse and spatialized information, tends to increase the control and precision of the results, conditioning the environment for the resistance characteristics of the materials and, therefore, the greater and lesser possibility of occurrence of movements of pasta. The difficulty in studying a large number of variables and the relationships between man and nature create unexplored opportunities for the use of urban space. The way in which these variables must be combined allows for a series of studies of potentials and risks, using qualitative decision support tools.

In the case in question, a study on a municipal scale was proposed, which has the advantage of indicating all areas with the potential to become a risk area based on relief, geotechnical parameters and annual precipitation. With this map, it is possible to superimpose the patterns of land use and urban occupation in a GIS environment, allowing an initial and indicative analysis for more energetic subsequent actions. The maps show the locations in the city that deserve attention from the government. With these data, the responsible agent can verify in loco the measures to be taken to solve potential problems. The greatest benefit of this methodology is the speed in analyzing a large area, the ease in integrating other databases and updating temporal information.

5 ACKNOWLEDGEMENTS

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