Mapping of risk areas of the municipal district of Viçosa, Minas Gerais, Brazil

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Abstract: Unplanned development on mountain-sides is one of the main problems faced by most Brazilian cities, and the city of Viçosa-MG, is no different. The municipal district has an irregular topography and is undergoing accelerated urbanization. This paper describes mapping of risky areas using geo-processing, as well as geotechnical characterization to inform the responsible authorities monitoring development of these areas. For the proposed mapping, geotechnical map builder software was developed to present the results in a clear, precise and accurate way, to show the information about the physical site being studied.

Résumé: Le métier désordonné sur des montagnes est un des problèmes principaux considérés par la plupart de villes brésiliennes. La ville de Viçosa-MG, n'est pas trouvée dans la situation différente. La zone municipale a une topographie irrégulière et traverse un processus accéléré d'urbanisation. Ce travail a le but de tracer des secteurs risqués en utilisant le geo-traitement, aussi bien que la caractérisation géotechnique pour fournir la subvention aux organes responsables dans la surveillance de ces secteurs. Pour tracer, un logiciel géotechnique de constructeur de carte a été développé, afin de présenter les résultats d'une manière claire, précise et précise, montrant la majeure partie d'informations sur l'emplacement physique qui est étudié. Mots clés: Système d'information géographique, métier urbain

Keywords: Geographic information system, urban occupation

INTRODUCTION

Urban development brings several problems, and rapid urban growth, mostly unplanned, creates and emphasizes inadequate infra-structure and land usage problems. To address one aspect of this problem, it is necessary to make a detailed survey of the variables that govern the erosion of natural mountain sides and their stability. This will allow potential hazards to be identified, indicate where development restrictions might apply and enable legal limitations to be established. It will also show where intervention should take place to prevent or remediate slope instability, employing appropriate structural or non-structural measures.

The importance of information regarding the physical environmental has been discussed for some years. One issue is the methodology to best represent variations of parameters in 3-D space. So, geotechnical mapping was developed, showing the most superficial soil and information on its geotechnical behavior, with associated physical environmental information such as: slopes, relief, soil classification, lithology, ability to use the soil, erosion and geological risks.

Besides assisting urban planning, this can be used to help preserve the environment, implement civil engineering works and in the general urban development. Therefore, geotechnical mapping represents anthropogenic influences on the physical environment graphically, viewing the mitigation of problems in the course of future activity and their prevention.

Advances in geographical information systems (GIS) associated with improved geo-processing techniques allow a geo-referenced database to be manipulated, providing an efficient tool for digital geotechnical decision-making. This paper presents software designed to improve digital geotechnical decision-making, so the results are presented in a clear, succinct and precise way, with as much information as possible.

AREA CHARACTERIZATION

The municipal district of Viçosa is located in the forest zone in Minas Gerais, Brazil, and has an approximate population of 70,000 inhabitants. The municipal district urban area is located at the co-ordinates 20°45’14” of latitude S and 42°52’54” of longitude W; it has an area of 299 km² and an average altitude of 649 m (above sea level). This area has a highland tropical climate with fresh rainy summers. The average precipitation is 1300 mm/year with maximum amounts from October to March. The topography of the urban area is formed by many hills with narrow valleys.

From the 1970s onwards, the town started unplanned and accelerated urbanization process with no planning for land use. Once the bottoms of the valleys were developed, mountainsides were occupied. Most of the sites developed during the decade of the 1970s were on areas with slopes greater than 30%.

According to Veira (1999), this process resulted in development dependent on the performance of steep cuts and fills placed without compaction on intervening low lying ground, all executed without technical follow-up. Today the unsafe situation of the population, and especially the poorest members, is for those that are forced to occupy the highest and steepest parts of the mountainside.

Urban growth has increased environmental degradation, with continual attacks against a good climatization, correct drainage, green areas, water-courses, and original topography. Figure 1 shows a slope in the São Sebastião district in Viçosa. It was selected as a central region in the municipal district, practically on a mountainside and with occupation, and no systematic geotechnical testing was performed to determine soil strength parameters.

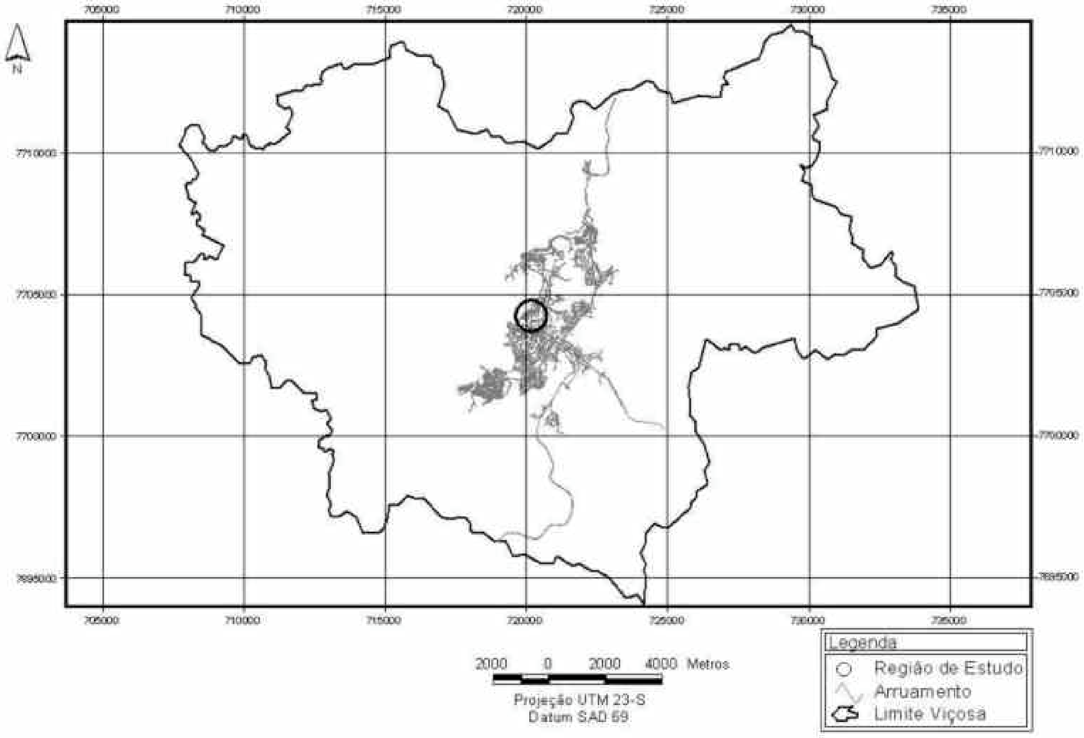

Figure 1. Study area

METHODOLOGY

The field work comprised preliminary data collection and recording to provide input to the data bank. Each test site was geo-referenced in UTM coordinates with a Global Positioning System (GPS), and the geometrical parameters (length, width and height) defined from a plainaltimetric topographic survey. The slope dip and direction, and inclination were measured with a geotechnical compass. Then, soil samples were collected and the slope site was photographed with a digital camera. Using the GPS coordinates, the test sites were located on a regional geo-referenced photograph.

Collected soil samples were submitted to geotechnical testing at the Viçosa Federal University, Soil Mechanics Laboratory. Tests were carried out to technical standards established by ABNT to determine parameters governing cut slope and natural mountainside stability.

Using elevation contours at 1 m spacing, obtained from the Sewer and Water Autonomous System (SAAE), a digital topographical model was generated, making slopeness letter generation and shadow analytical model creation possible. For these spatial data treatments, the software ArcGIS 8.2, ESRI was used.

The specific weight (γ), the cohesion (c) and friction angle (ϕ) were determined in the laboratory, and together with the slope geometry, they allowed the analysis of its stability. The slope factor of safety coefficient was obtained following the Bishop, Fellenius and Morgenstern-Price methods, using software SLOPE/W version 4.21, 1998, from GEO-SLOPE International Ltda. Though it is easy to use and produces good results, the SLOPE/W platform does not allow new functions to be added, and this was considered to be a disadvantage when only this software is used for the stability analysis. For 3-dimensional analysis of a slope in more critical conditions, a digital model was created, using software 3DStudio Max ® R3, Kinetix. This model allows the slope to be visualized from several different angles.

The Geographic Information System laboratory (LabSIGEO) of the Civil Engineering Department at Viçosa Federal University has developed Geocamp software. This allows the factors that determine stability of cut slopes and natural mountainsides to be visualized. The software combines information such as coordinated locations and photographs of each test site, with outputs generated from the ArcGIS 8.2, 3dStudio Max ® R3 and Slope/W programs. Each mapped point maybe interrogated by users: for example the urban environment point location, its slope class, sketch layout, geotechnical characteristics, photographs and 3-dimensional views of the slope.

The software tools in which the data for visualization on the Geocamp were processed are described below.

Data treatment on the Arc GIS 8.2

Data treatment on the ArcGIS firstly has comprised regional contouring for the topographical digital model – MDE generation with the topogrid interpolator of the Arc-Info module. Then on the Arc-Map, and using the topographical digital model, the analytical shadow model (hillshade) was generated, with an inclination angle of 45° and azimuth of 315°. This model was the base for the point visualization mapping together with the study area photograph. The image presented on Figure 2 shows the occupation of the mountainsides in the city of Viçosa.

Figure 2. Mapping region aerial photograph showing occupation of mountainsides.

From the MDE, a slope map was generated showing percentage slope. The studied region was divided into slope classes up to 30% slope. This slope value is critical with regard to urban development, as specialized design subject to regulatory approval is then required. Finally, the locations of areas with slopes that provide a hazard to the population were identified.

Modeling with 3dStudio mase R3.

3-dimensional models of slopes found in more critical situations in the field were developed. This modeling was carried out using the software 3d Studio Mase R3, kinetics, which consists of a tool that is able to model any object from geometric data relevant to it, as well as generating animation.

At the modeling phase, a basic object with dimensions similar to those of the slope was firstly structured. Based on the slope characteristics and photographs, refinement of the of the basic object was made, so that it started to gradually the real slope characteristics. To visualise the slope from any view point it is possible to vary the camera position. It should be recognized that the modeling process should be coherent, so that the information obtained from model analysis is identical to analysis in the field.

Proper modeling is critical, not only modeling of the form of slope, but also so it can be used in software that performs 3-dimensional analysis, to obtain information regarding rupture wedges, weakness planes, and safety factors. It is possible continuously to update and improve the animation based on the model, for slope condition visualization, just as if there were a person walking around it, enabling visual inspection that previously could only be made in the field.

Analysis with slope/W version 4.21

Despite not allowing the addition of new functions, for example by altering the programming language to adjust for specific situations, slope W version 4.21 runs on MS Windows, and performs stability analyses using parameters that may be easily measured in the laboratory, such as the material specific weight, the friction angle and cohesion, and in the field, such as the measured mountainside geometry.

Slope stability analysis made using Slope/W comprises two steps: -

1. The module Slope/W DEFINE is used to draw the slope geometry based on the data obtained from the area plainaltimetric survey. For this an adequate scale should be selected for the sketch section drawn. Slope height and angle are relevant parameters in the analysis and for this reason they must be determined with precision.
2. Then the soil properties that were determined in the laboratory are input, again using the module DEFINE of Slope/W.

The analysis determines centre and radius of potential sliding surfaces, and from these data, the program determines the factor of safety; different analysis methods might be employed, for example, Bishop and Fellenius, among others are available.

A useful aspect of Slope/W is the module CONTOUR version 4.21, which indicates where the slip circle with lowest factor of safety occurs.

GEOCAMP

The object of creating and implementing GeoCamp was the development of software that integrated all the spatial consultation potential of a SIG tool with the functions of a flexible and guided geological and geotechnical study record system. The system is user-friendly, allows intensive use of geo-referenced digital graphic information and great flexibility in term of structures and data formats, as well as in the level of detail definition of the graphic information.

Used development tools

GeoCamp was developed through Delphi® (Borland) together with two auxiliary modules MapObjects® from Environmental Systems Research Instutute (ESRI), for the spatial consultation and map presentation, and OPUS®, for descriptive data bank management implemented by means of Access® (Microsoft Corporation). The link between the graphic and the descriptive data bank was made with the Spatial Query of the MapObjects®. Once the points were ordered and sequentially digitized, the produced attribute link consisted of the co-relation between the point identifier and the data bank identifier.

Tool use process

To be able to consult the data bank and facilitate spatial visualization, a graphic interface was developed on MapObjects containing the following information – plans, analytical shadow model, hydrography, Plain Projection System net (UTM), and observation points in the field. Graphic scale and zoom were included to facilitate consultation and visualization.

From the opening screen, the user has the following interface with the system: the user chooses the point of interest and the program returns the address and date when the characterization was done. Then, the user can consult the constant descriptive data in two windows, point (1) data, and point (2) data; consult the geological structures found in the point or area (foliation, fractures and imperfections, etc); visualize the layout, point or area photographs and 3-dimensional model as shown in Figure 3.

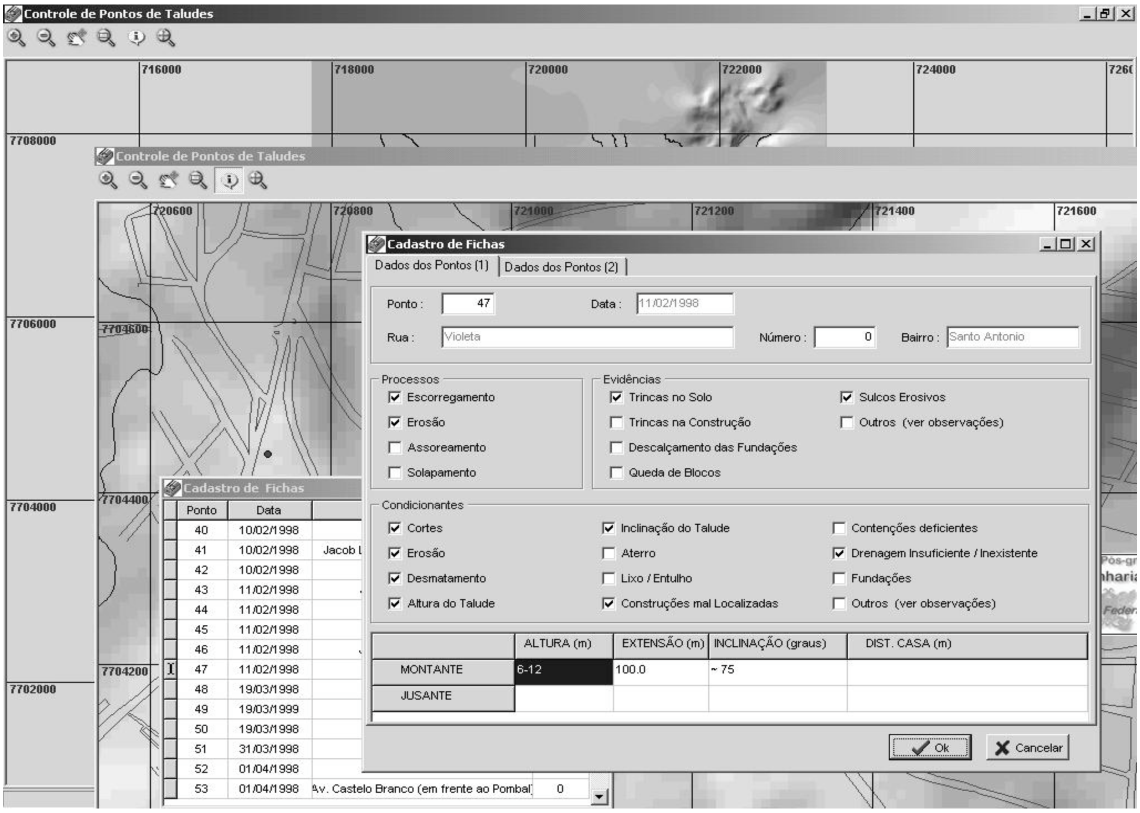

Figure 3. Consultation to the data of a point

Descriptive information related to the geological process, field evidence, main geological condition, previous damage and geological hazard are presented in the data bank. Figure 4 presents a screen of the system recording consultations to the data bank of geotechnical cards. The insertion of graphic elements, like sketches and digital photographs, was included to incorporate functionalities of analysis to the tool.

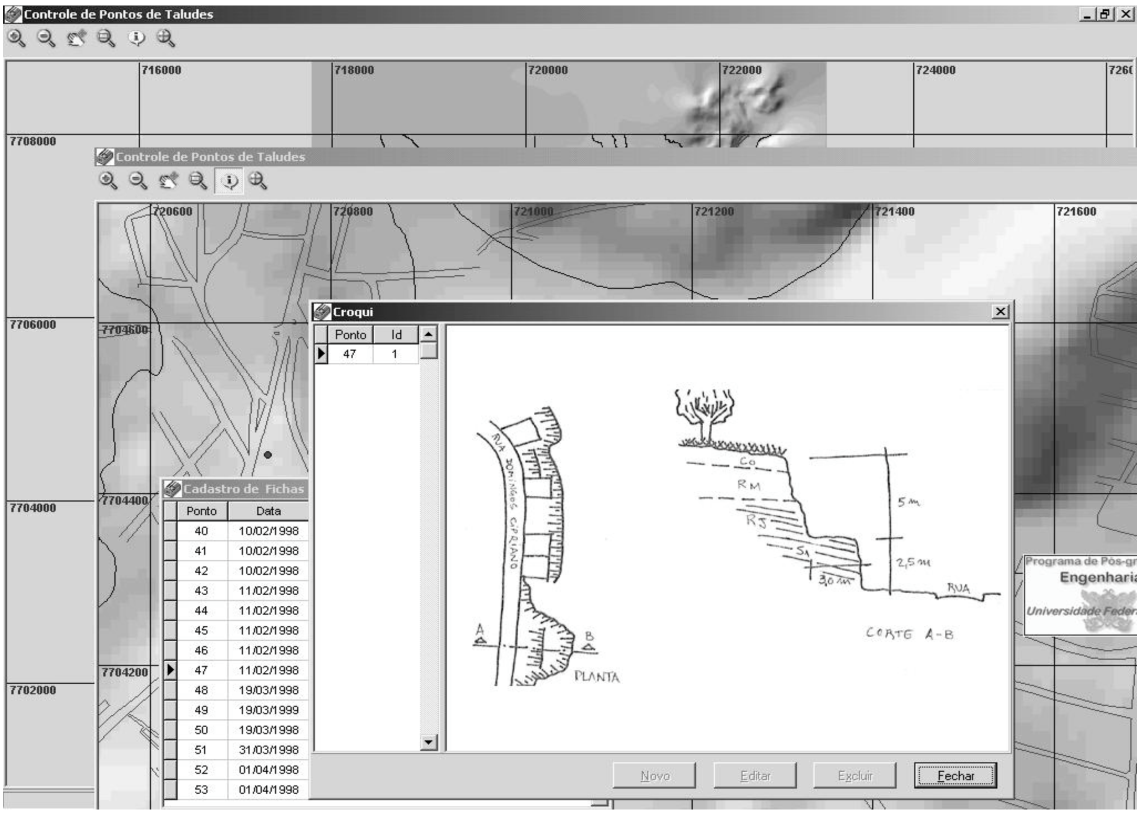

Figure 4. Geological structure data bank consultation with cross section visualization.

CASE STUDY

The developed tool was applied to the study of erosive process and instability of slopes present in Viçosa urban area to show how it might be adapted to any other region. Thus, several types of evidence relevant to local urban problems were observed, as follows:

- Cuts in slopes with high slope angle;
- Houses built directly close to cuts and with no protection;
- Inappropriate occupation at stream and river margins;
- Inadequately installed infra-structure in new lots.

Mapping of a district with critical conditions was performed with a view to research alternative land occupation and usage, and the effect of proposed fiscal control measures. Figure 5 show a consultation to the photograph file of one of the critical points.

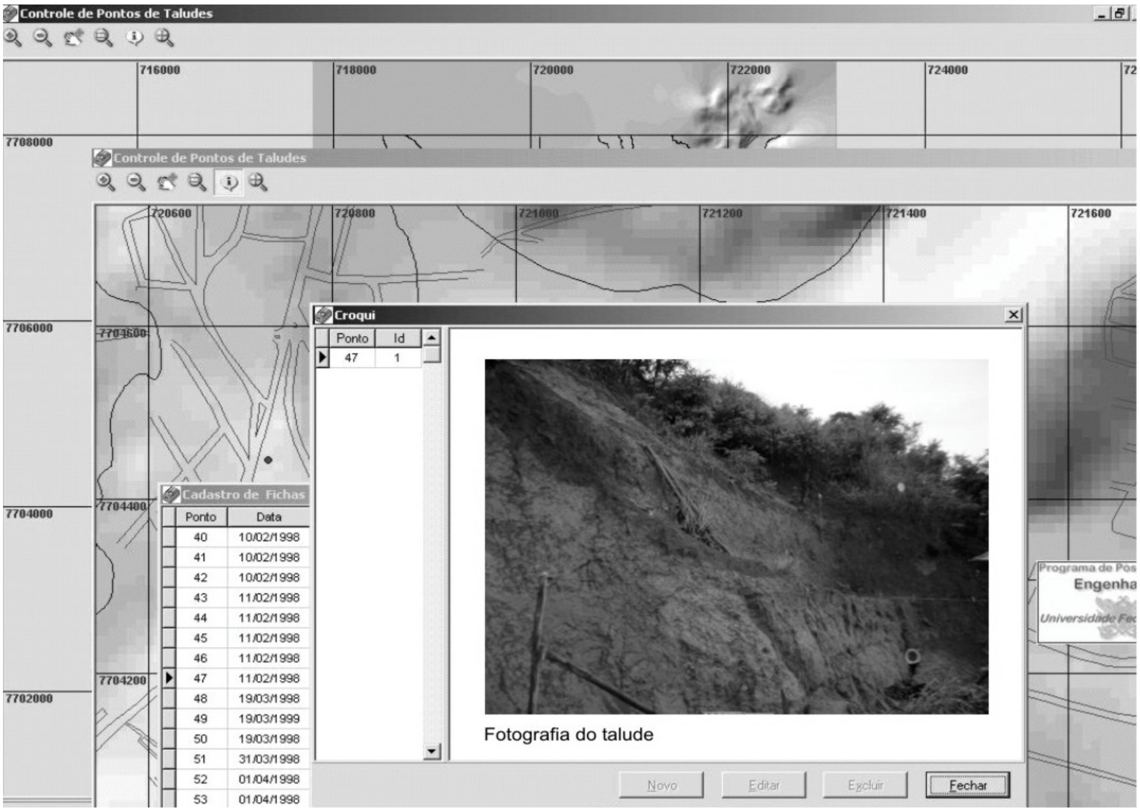

Figure 5. Geological structure data bank consultation with photograph file visualization

The software also allows the 3-dimensional structure to be consulted (Figure 6), enabling its visual analysis and the result of the studied slope stability analysis (Figure 7).

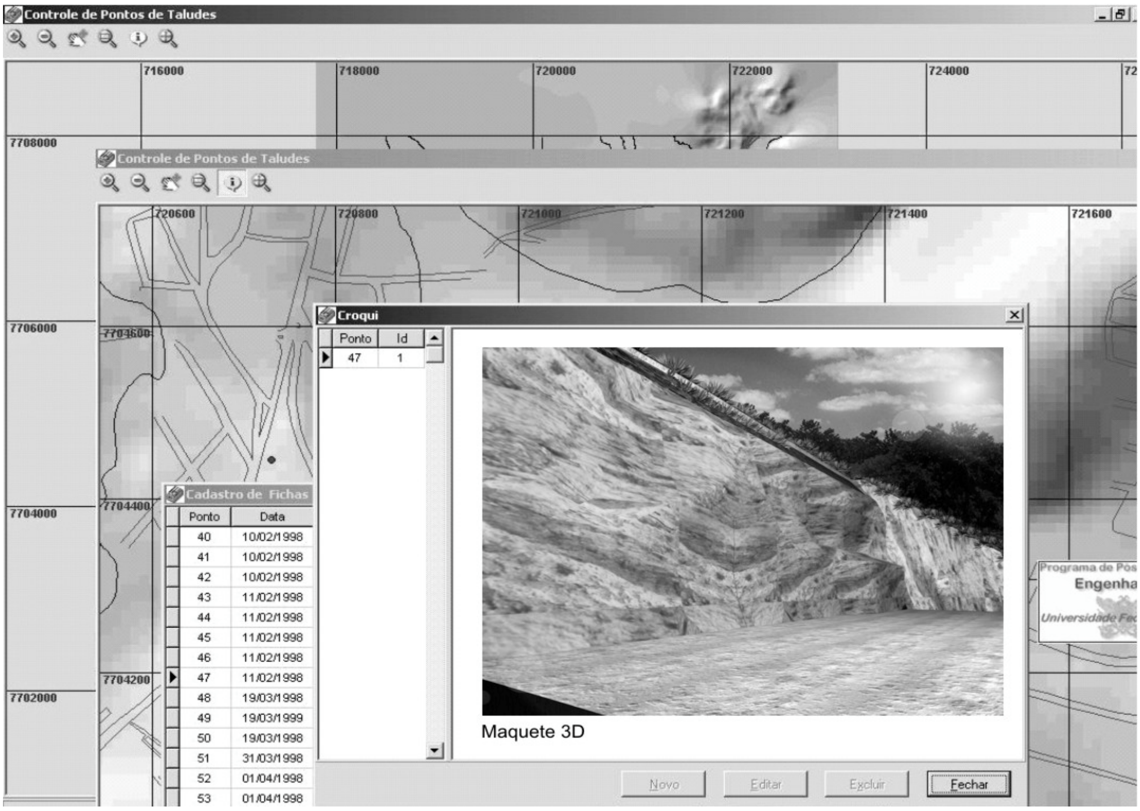

Figure 6. Slope 3-dimensional model

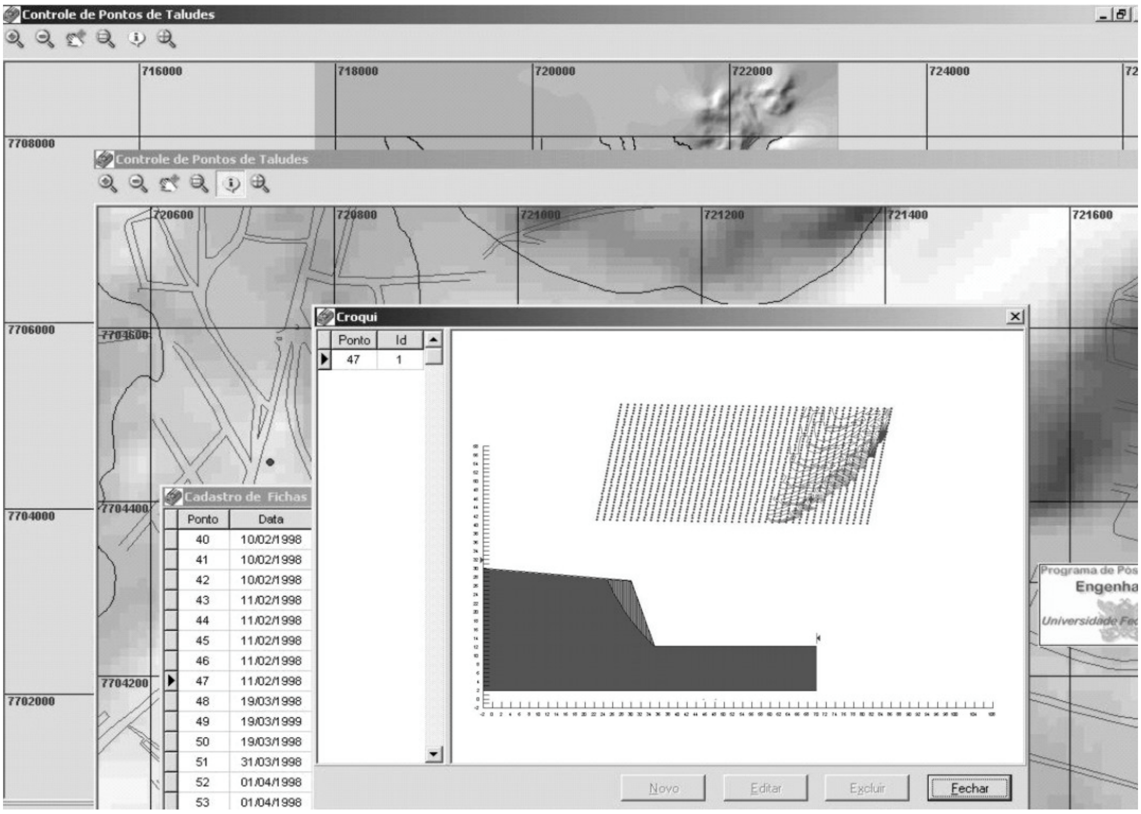

Figure 7. Slope stability computer analysis with Slope/W

CONCLUSIONS

The district of São Sebastião has unplanned residential development and is mostly located on slopes steeper than 30%, suggesting it is a high-risk region for housing. Software was developed and implemented based on a methodology that employed spatial data, with mapping of geotechnical characteristics at critical points. Data was integrated to produce a high performance system with great flexibility and technical viability for use in spatial risk assessment.

The geotechnical data incorporated in the software improves the consistency of the analysis, because slope angle and point spatial distribution on their own do not provide sufficient information to assess the risk to the population.

The final product presents the main content, with quantitative geotechnical information, and allows predictions for direct use in the specify study and different project phases, as well as presenting a spatial variability represented by a group of information associated to a functional hierarchy and, therefore, to a step sequence. In this way, the tool considers the cost and space usage optimization and prevention aspects for urban and territorial planning purposes, and so, can be relevant to a many different types of land occupation and usage.

When it is considered that many houses are located on steep slopes with unfavorable geotechnical characteristics, population removal is recommended to minimize the consequences of possible failure of these mountainsides.

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REFERENCES

VIEIRA, V. 1999. Caracterização Preliminar do risco geológico da Área Urbana de Viçosa (MG). 1999. 152 f. Dissertação (Mestrado em Engenharia Civil) – Departamento de Engenharia Civil, Universidade Federal de Viçosa, Viçosa.

BAPTISTA, E.I.; LIMA, D.C; BUENO, B.S. 1998. Caracterização geotécnica das formações superficiais de solos de Viçosa (MG). 11° Congresso Brasileiro de Mecânica dos Solos e Engenharia Geotécnica, Brasília.

NATALI, P.P. 1999. Carta de Riscos de Escorregamentos de Ponte Nova (MG). 1999. 180 f.. Dissertação (Mestrado em Engenharia Civil) - Departamento de Engenharia Civil, Universidade Federal de Viçosa, Viçosa.

QUINTEIRO, F.Q.L. 1997. Levantamento do uso da terra e caracterização de ambiente da bacia hidrográfica do Rio Turvo Sujo com a utilização de aerofotos não convencionais. 1997. 91 f.. Dissertação (Mestrado em Engenharia Civil) - Departamento de Engenharia Civil, Universidade Federal de Viçosa, Viçosa.

RAMALHO, G.G.C. 1994. Mapeamento geotécnico de Viçosa com o uso dos sistemas de informações geográficas. 1994. 110 f.. Dissertação (Mestrado em Engenharia Civil) - Departamento de Engenharia Civil, Universidade Federal de Viçosa, Viçosa.

VAN WESTEN, CEES. J. 1993. Training Package for Geographic Information Systems in Slope Instability Zonation. Part 1: Theory. Enschede: UNESCO, 245p.

CERRI, L.E.S. & AMARAL, C.P. 1998. Riscos Geológicos. In: OLIVEIRA, Antônio Manoel dos Santos; BRITO, S.N.A. de (Org.) Geologia de engenharia. São Paulo: Associação Brasileira de Geologia de Engenharia, 301-310.

ZUQUETTE, L. V.; GANDOLFI, N. 2004. Cartografia Digital. São Paulo: Oficina de Textos, 180p.