UFU

Brazilian Geographical Journal: Geosciences and Humanities research medium

ARTICLES/ARTIGOS/ARTÍCULOS/ARTICLES

Risk Mapping Associated With Mass Movements in Viçosa (MG) Urban Area

Master Leandro Antônio Roque
Geographer, Civil Engineering Department, Universidade Federal Viçosa, Campus Universitário, Viçosa (MG), Brazil, ZIP: 36570-000. Phone: +55 31 38991481; fax: + 55 31 38991482. E-mail: leandraroque1@hotmail.com

Doctor Joel Gripp Junior
Surveying Engineer, Assistant Professor, Civil Engineering Department, Universidade Federal de Viçosa, Campus Universitário, Viçosa (MG), Brazil, ZIP: 36570-000. Phone: +55 31 38991481; fax: + 55 31 38991482. E-mail: jgripp@ufv.br

Doctor Eduardo Antonio Gomes Marques
Geologist, Associate Professor IV, Civil Engineering Department, Universidade Federal de Viçosa, Campus Universitário, Viçosa (MG), Brazil, ZIP: 36570-000. Phone: +55 31 38991481; fax: + 55 31 38991482. E-mail: emarques@ufv.br

ARTICLE HISTORY

Received: 23/03/2014
Accepeted: 10/11/2014

ABSTRACT

Viçosa (MG) presents an undulating terrain with rounding tops hills and steep slopes and thick soils. These characteristics, combined with a process of disordered occupation, resulted in several landslides and erosions processes in recent years. This paper presents the results of a land use and a mapping of those urban risk areas, using the methodology proposed by the Brazilian Ministry of Cities. The study area covers all the 51 city urban districts. A total of 101 risk points and 45 risk areas were identified. All risk points and risk areas were ranked throughout the criteria defined on the method. The results proved that the method is a reproducible, reliable, efficient, low cost and easy to apply procedure to determine risk areas. As a result, georrefered information and maps on GIS environment were produced for the entire study area, in a way that can be simply used by municipal authorities.

PALAVRAS CHAVE:
Risco
Áreas de Risco de Escorregamentos
Ocupação Urbana

REUMO: Mapeamento das Áreas de Risco Associados a Movimentos de Massas na Área Urbana de Viçosa-MG. Viçosa (MG) apresenta um relevo acidentado marcado pelos topos de morros e encostas íngremes, o que, aliado a um processo de ocupação desordenada resultou no surgimento de áreas de risco de escorregamento. No presente trabalho apresentam-se os resultados de um mapeamento do uso do solo e das áreas de risco na área urbana do município, utilizando-se uma metodologia modificada a partir da proposta do Ministério das Cidades. A área em estudo abrange 51 bairros do município, nos quais foram mapeados 101 pontos e delimitadas 45 áreas de risco. Todos os pontos e áreas de risco foram hierarquizados de acordo com os critérios propostos na metodologia utilizada. A metodologia utilizada mostrou-se eficiente, de baixo custo e de fácil aplicação à área de estudo, tendo sido produzidas uma série de informações e mapas georreferenciados, em ambiente SIG (Sistemas de Informação Geográfica) de fácil atualização e manipulação.

RESÚMEN:
Riesgo
Zonas de Riesgo de resbalamiento
Ocupación Urbana

RESÚMEN. RISK MAPPING ASSOCIATED WITH MASS MOVEMENTS IN VIÇOSA (MG) URBAN AREA. Mapeo de las zonas de riesgo asociados a movimientos de masas en las zonas urbanas de Viçosa-MG. La ciudad de Viçosa cuenta con un relieve accidentado marcado por las cimas de los montes y cuestas empinadas, lo que, combinado con un proceso de ocupación desordenada resultó en el surgimiento de áreas de riesgo de resbalamiento. En este artículo presentamos los resultados del mapeo del uso del suelo y de las zonas de riesgo en el área urbana, utilizándose una metodología creada a partir de la propuesta del Ministerio de las Ciudades. El área de estudio abarca 51 barrios de la municipalidad, en los cuales fueron mapeados 101 puntos y delimitadas 45 zonas de riesgo. Todos los puntos y zonas de riesgo fueron jerarquizados en consonancia con los criterios propuestos en la metodología utilizada. La metodología utilizada se mostró eficiente, de bajo costo y de fácil aplicación en el área de estudio, habiendo sido

producidas una serie de informaciones y mapas georreferenciados, en ambiente SIG (Sistemas de Información Geográfica) de fácil actualización y manipulación.

Introduction

Geological and geotechnical mapping of risk areas is an important tool of territorial/environmental management (Gomes et al., 2007), as it can help the prevention of geological accidents through the identification of areas with potential for occurrence of landslides, erosion and subsidence; as well as the most appropriate areas for occupation.

According to Tominaga (2007), the expression *risk area* is slowly being incorporated into the vocabulary of the Brazilian population, through news about the several accidents associated with landslide and floods, during rainy periods, very common on occupied areas of mountain hills, deep of valley, and in major urban centers, especially in Southeastern Brazil.

Both rock and soil landslides and floods are the main phenomena related to natural disasters occurring in Brazil, and they both are associated with intense, prolonged and frequent rainfall events, most commonly – but not exclusively, during the rainy season. While floods cause major economic damage, landslides are responsible for the greatest loss of life (CARVALHO & GALVÃO, 2006).

The present study aimed to assess the current conditions of land use and define and prioritize areas of geological and geotechnical risk of mass movements in the urban area of Viçosa (MG), covering all its 51 districts, as presented on the map of Figure 1. The focus was to identify points and areas of mass movements risk, through the application of a methodology suggested by the Brazilian Ministry of Cities, which allows a mapping that has low complexity in determining and ranking risk areas, resulting in a reduced mapping and interpretation cost.

Also, assess and predictive studies of the current situation of urban occupations and areas proposed for urban expansion are intended to recognize and propose solutions to prevent the inadequate occupation.

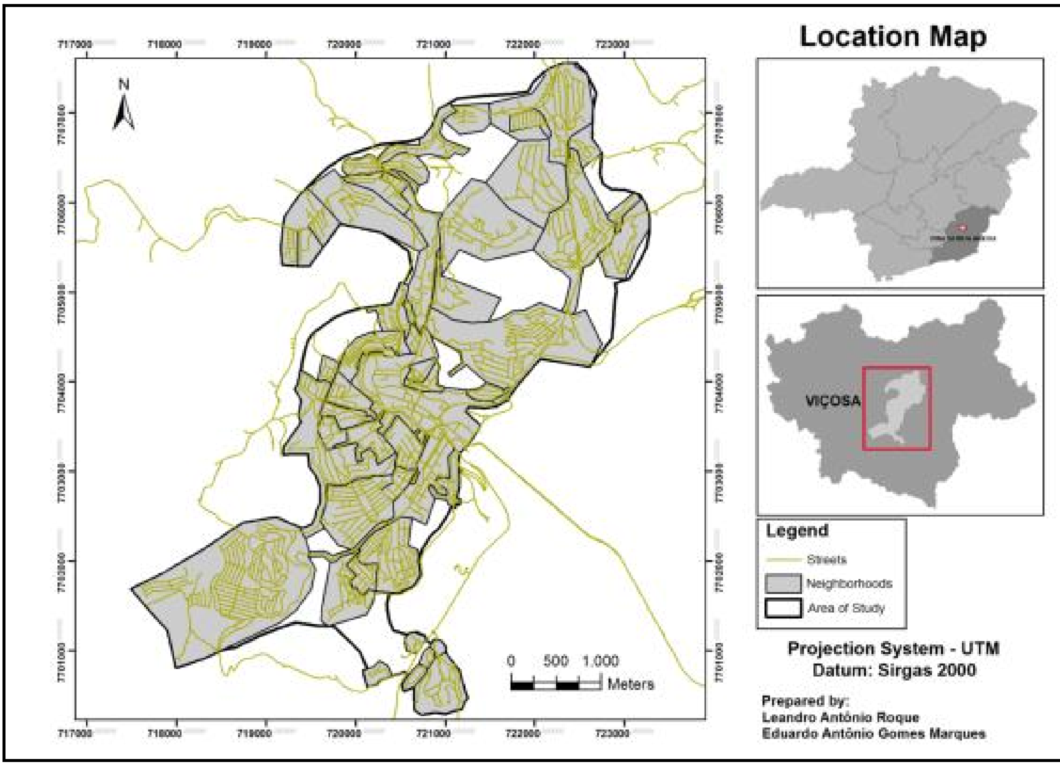

Figure 1: Location of Viçosa and its Districts under study. In white, areas not occupied within Viçosa urban area.

Materials and methods

For mapping of risk areas associated to mass movements within Viçosa urban area all the information related to its physical characteristics obtained from previous academic and public studies were integrated with information produced during the present research, mainly those obtained throughout mapping and registration of points/areas of risk. Thus it was possible to create a reliable digital database, integrated into a Geographic Information System (GIS).

The GIS used in this work was the software ArcGIS® version 10.0 produced by ESRI (*Environmental Systems Research Institute*).

The present research has begun with a literature search on its theme, especially on recent methodologies for mapping risk; and in order to provide an inventory of existing work in the study area. The basic map used on the project was based on the Viçosa digital cartographic database, obtained Viçosa (2009), with all its basic features, including district limits, street names and position and local reference landmarks, such as schools, hospitals, churches, among others. For characterization of altimetry, contours with contour interval of 5 meters, kindly provided by the GIS Laboratory, Department of Soil Science (DPS), Universidade Federal de Viçosa (UFV) were used. The curves were generated by stereoscopic analysis of pairs of images from high-resolution Ikonos satellite images of the study area, dated 2007, acquired by the PSA Project (Water Safety

Plan, Universidade Federal de Viçosa), and used under permission of the Department of Civil Engineering (DEC) (PORTES, 2008).

Previously to field mapping, a search on the Civil Defense Department of Viçosa City Council and in local newspapers was done to collect information on previous mass movements, margin erosion and its consequences, and to determine which were the neighborhoods (districts) with a historical record of landslides. Unfortunately, Viçosa Civil Defense Department and Viçosa City Hall do not have a historical background record of mass movements occurred in Viçosa area.

Coordinates of the mapped geological-geotechnical risk points in the field were defined through a navigation GPS (Global Positioning System) Garmin Model OREGON 550, with positioning accuracy of 3 to 8 meters, which also allows taking georeferenced photographs of all points. These risk points defined were accompanied by a detailed registration form, in which all the information necessary to assess the degree of geological-geotechnical risk, was summarized and a initial classification of the degree of risk was reached.

The verification of the accuracy of the referred mapped points and of the limits of each polygon defining a risk area was then draw over a Ikonos (2007) georeferenced and orthorectified image, with spatial resolution of 1.0 m, with color composed by three bands: three , two and one (RGB 3-2-1).

The risk mapping work was done in two steps. Initially, using the registration form modified by the authors based on the Ministry of the Cities suggestion an on their previous experience (Figure 2) all identified risk points were registered and inserted in a digital databank. It is noteworthy that the development of the registration form was based on the training course in mapping and risk management prepared by the Brazilian Ministry of Cities in 2007. The form includes several and important information, as presented on Figure 2, for the determination of risk and identification of the point/area.

During field mapping, all streets of all 51 districts that comprise the study area were covered, in order to observe signs of mass movements, erosion processes or houses at risk. For those locations where hazardous conditions or for those points representing the situation of a surrounding area, a risk point was defined using GPS. For each point the form was filled in, photos were taken and, finally, the degree of risk of the point was determined based on the criteria defined on the method and described ahead.

To determine the degree of risk at each point, a scale with three levels - considering the probability of occurrence was used, based on the geological and geotechnical information, as: Low (R1), Medium (R2), and High (R3).

Registration Form

Professional: | Date:

Point No.	Geographic Coordinates (WGS 84):		Photos No.
	Latitude:	Longitude:	

Location:

Address | No.

Complement | Neighborhood

Description Point

Slope

- Natural
- Artificial

Dist. from the house to the base of the slope ___ m | Inclination | Height ___ m

Dist. from the house to the top of the slope ___ m | Extension ___ m

Natural Drainage	Drainage Buit	
Efficient / Deficient	Efficient / Deficient	Superficial / Deep

Crawling Vegetation	Woody Vegetation
Dense / Sparse / Medium / Absent	Dense / Sparse / Medium / Absent

Occupation

Urbanized / Disordered / Absent | Dense / Medium / Sparse

Constructive Default

Low / Medium / High

Type Occurrence (Accidents)

- Superficial Slip
- Bearing Blocks
- Exposed Foundation
- Erosion
- Deep Slip
- Cracks in Land
- Collapse the Structure Built
- Steps Abatement
- Displating Rock
- Cracks in House
- Other

Date of Occurrence | Demage Caused

Causa Provável ou Agente Potencial Indutor:

- Cut
- Insufficient Contentions
- Garbage or Rubbish
- Floods
- Vibrations
- Heavy Rains
- Landfills
- Localised Barely Construction
- Desforestation
- Water Percolation
- Geological Strutures
- Erosion
- Deficients Drainagens
- Other

Geotechnical - Geological Risk

Dregree of Risk: Low (R1) / Medium / High (R3) | Nature of Risk: Potential / Current

Probable Damage

- People
- Contruction
- Infrastructure
- Houses
- Street
- Other

No. House Involved

Sketches and Photos

Figure 2: Example of a Datasheet Registration Form.

Based on the information collected before, a risk zoning was developed in order to delimit risk areas. This zoning was done at the office, mainly based on information collected on risk points and on analysis of information of registration forms. After that, a previous zoning map was produced. This map was then taken to field inspection and validation, and the limits and risk level of each sector were reviewed.

Definition of field characteristics of the occupied risk areas allowed the determination of susceptibility risk for non-occupied areas. The main factors used on this approach were slope, soil type, vegetation and presence of previous mass movement or erosion.

For zoning risk, 4 degrees (levels) of risk were used: No Risk (R0), Low Risk (R1), Medium Risk (R2) and High Risk (R3). Determination of risk levels for each points or area was based on the qualitative evaluation presented on Table 1, adapted from a proposal by the Brazilian Ministry of Cities in 2007 (BRAZIL, 2007) criteria. Besides the description of the degree of risk, the authors have used colors in order to facilitate the visualization of point and risk areas on the final map.

The changes made on the original Brazilian Ministry of Cities were:

a) Inclusion of the *No Risk (R0)* class for areas where no geological and geotechnical conditions to the occurrence of landslides were observed;
b) Exclusion of the *Very High Risk (R4)* class as the authors have considered the differentiation between *High Risk Areas (R3)* to *Very High Areas (R4)* somewhat confusing. In the present study all these areas were classified as R3, where the need for intervention is immediate. As the used method is rather qualitative and do not involve any geotechnical testing, the authors suggests that definition of R4 areas should be based on these tests in order to provide a more reliable definition of these areas, as they would have major priority on the solution of the problem.

Grade probability	Description
R0 No Risk	1. Geological and geotechnical predisposing conditions (slope, terrain etc.) and the level of intervention in this point/area has no potential for the development of landslides and erosion processes. 2. Signal/feature/evidence (s) of instability not observed. There is no evidence of instability processes both on slopes and drainages margins. 3. It is assumed that, maintained the existing conditions there are no expectation of occurrence of destructive events during a normal rainy season.
R1 Low Risk	1. Geological and geotechnical predisposing conditions (slope, terrain etc.) and the level of human intervention in this sector has low potential for the development of landslides and erosion processes. 2. Some incipient signal/feature/evidence (s) of instability is observed at slopes and drainage margins. Instability processes are in a initial development stage. 3. Maintenance of current conditions reduces the possibility of destructive events to occur, even during episodes of intense and prolonged rainfall in rainy season.
R2 Medium Risk	1. Geological and geotechnical predisposing conditions (slope, terrain etc.) and the level of human intervention in this point/area results in a medium potential for the development of landslides and erosion processes. 2. Relevant(s) signal/feature/evidence(s) of instability (cracks, stepped rebate on slopes etc.). Instability process in full development. Monitoring of process evolution still being possible. 3. Maintenance of current conditions allows the possibility of destructive events to occur, during episodes of intense and prolonged rainfall in rainy season.
R3 High Risk	1. Geological and geotechnical predisposing conditions (slope, terrain etc.) and the level of human intervention in this point/area results in high potential for the development of landslides and erosion processes. 2. Relevant(s) signal/feature/evidence(s) of instability (cracks, stepped rebate on slopes, cracks on buildings, inclined trees and towers, failure scars, erosion scars, proximity of drainage margins etc.) are expressive and commonly present. Instability process in an advanced stage. 3. The possibility of destructive events to occur is high for current conditions, during episodes of intense and prolonged rainfall in rainy season.

Table 1: Risk hierarchy criteria description (Based on Brazilian Ministry of Cities, 2007).

Results

An update of the historical record of recent events of gravitational mass movements and margin erosion at Viçosa urban area, initially conducted by Costa (2006) was done and the results area presented on Table 2 for the period 1985 to

2012. This historical record was important because it allowed an initial recognition of mass movement sites within the study area. As mentioned before, the lack of previous information on both Viçosa Civil Defense Department and Viçosa City Hall, was a major problem for having a reliable historical database for the beginning of the proposed study and marks the negligence of local authorities for this problem.

In Table 3 are presented the risk areas and points mapped (Table 1) in each one of the 32 districts for which those elements have been identified. On the remaining 19 districts there was no evidence of mass movements. Emphasis should be given to the large number of risk point in the districts of Nova Viçosa, in which were registered 2 points of low risk, medium risk points 4 and 9 points at high risk; and the city centre, with 5 points of low risk, medium risk points 2 and 8 points at high risk.

It must pointed that the higher number of medium and high risk points in relation to low risk points is an effect of the field mapping and the used method. As long as there were several other *Low Risk Points (R0)* identified during mapping, but as those points presented similar geological and geotechnical characteristics, these points were all put together in a same *Low Risk Area* and only some of them were use to represent the general aspects related to geological-geotechnical risk characetristics.

Also, no risk points were defined during field mapping. But those areas that attend the criteria presented on Table 1 were delimitated as *No Risk Areas*.

In Table 4 are presented the number of risk points for each Viçosa district, in order to identify if there was any districts with more risk points. Each risk point was numbered so as to facilitate their location on the map of Figure 3.

Year	Location	Socioeconomic losses
1985	Several Viçosa districts	500 people left homeless, landslides and house collapsing elsewhere in the city
1986	Vau Açú district Local Road Viçosa-Paula Candido.	Bridge collapse disrupting traffic from Viçosa to Belo Horizonte (State capital) Landslide on the local road Viçosa Paula Candido
1987	Fatima and Vale do Sol districts	Landslides, affecting several houses, no material losses
1988	Rua dos Passos	Wall collapse, no material loss
	Alto Santa Clara	Partial collapse of residence
1990	Nova Viçosa	Collapse of Residence - 1 death
1991	Bom Jesus	Collapsing houses - 18 people homeless
	Morro do Café, Rua Santana Street, Aimorés and Travessa Ênio	Several house collapses with material losses – no victims
1992	São Sebastião	Landslide - 1 home damaged
1993	High parts of Rua Santana	Lanslide – no victims
1995	Nova Viçosa	Landslide-48 homeless people
1997	Several Viçosa districts	45 – Total house collapse; 154 – Partial house collapse and 61 people homeless
1998	Nova Era and Amoras	Flooding and landslide
2000	Sagrada Família	2 houses collapsed in the high part of the neighborhood
2004	Avenida Marechal Castelo Branco.	Rock falling blocks
	Rua dos Passos	Landslide
	Vau Açú	House collapse – 5 people homeless
2005	João Brás, Silvestre and Ramos	Several landslides – no victims
2006	Santo Antônio	Partial house collapse
2007	Bom Jesus, Sagrada Família, Estrelas, Fuad Chequer, Santa Clara, São Sebastião, Boa Vista and Nova Era	Landslides, walls and houses collapses - 16 homeless families
2008	Bom Jesus, Carlos Dias, Silvestre and Vau Açú	Landslides – no victims
2009	Rua dos Passos, Rua Milton Bandeira, Fátima and Santa Clara.	Landslides, houses partial collapses – no victims
2011	AV. Santa Rita and Rua Dona Gertrudes.	House partial collapse, landslide - no victims
2012	Several Viçosa districts, including Centro (Downtown).	74 homes with partial collapse, 5 residences with total collapse and 66 homeless people. No victims

Table 2: Historical record of recent gravitational mass movements in Viçosa-MG. Source: Folha da Mata Journal (1985-2012).

District	Risk Points			Risk Areas		
	R1	R2	R3	R1	R2	R3
Arduino Bolívar	0	0	2	0	1	0
Barrinha	0	0	0	1	0	0
Bela Vista	0	0	1	1	0	1
Betânia	0	0	4	0	0	2
Boa Vista	0	1	0	2	1	0
Bom Jesus	0	1	3	1	0	3
Centro	5	2	8	4	2	3
Conceição	0	1	0	0	0	0
Cond. Monte Verde	0	0	1	0	0	0
Estrelas	0	0	2	1	1	0
Fátima	0	3	2	2	0	1
Fuad Chequer	0	0	1	0	1	0
Inácio Martins	0	0	1	0	0	0
J.K	0	2	0	0	1	1
João Braz	0	3	2	1	2	0
João Mariano	0	0	0	0	1	0
Liberdade	0	1	1	0	1	0
Maria Eugenia	1	0	2	1	0	0
Nova Era	0	0	2	1	0	1
Nova Viçosa	2	4	9	2	2	2
Romão dos Reis	0	1	0	0	0	0
Sagrada Família	0	1	6	1	1	1
Sagrado Coração de Jesus	0	0	1	0	0	0
Santa Clara	0	3	5	0	1	1
Santo Antônio	0	0	1	2	0	0
São Sebastião	0	1	3	1	1	0
Silvestre	1	0	1	1	0	1
União	0	0	0	0	1	0
Vale do Sol	0	1	0	0	1	0
Vau Açu	0	0	1	1	1	0
Vereda Do Bosque	0	2	2	0	0	1
Violeira	0	1	0	0	0	0
TOTAL	9	28	61	23	19	18

Table 3: Number of points and risk areas by district.

District	Point Risk Class and Id Number			TOTAL
	R1	R2	R3	
Arduino Bolívar			31; 32	2
Bela Vista			12	1
Betânia		74	53; 70; 71; 73	5
Boa Vista	101			1
Bom Jesus	16	15	13; 14; 81	5
Centro	2; 6; 25; 26; 90	1; 8; 9	7; 27; 28; 37; 41; 42; 87; 99	16
Conceição		80		1
Cond. Monte Verde			44	1
Estrelas		21; 22		2
Fátima		68; 69; 78	75; 79	5
Fuad Chequer			40	1
Inácio Martins			29	1
J.K		52; 71		2
João Braz		84; 85; 95	11; 83	5
Liberdade		86	96	2
Maria Eugenia	46		45; 47	3
Nova Era			30; 83	2
Nova Viçosa	77; 76	57; 61; 62; 65	56; 58; 59; 60; 63; 64; 66; 67	14
Romão dos Reis		43		1
Sagrada Família		23	17; 18; 19; 22; 24	6
Sagrado Coração de Jesus			93	1
Santa Clara		48; 51; 94	49; 50; 55; 54; 88; 89	9
Santo Antônio			10	1
São Sebastião		91	34, 35, 36	4
Silvestre	98		97	2
Vale do Sol		39	92	2
Vau Açu			100	1
Vereda Do Bosque		4; 9	3; 5	4
Violeira		82		1

Table 4: Location and ID number of risk points.

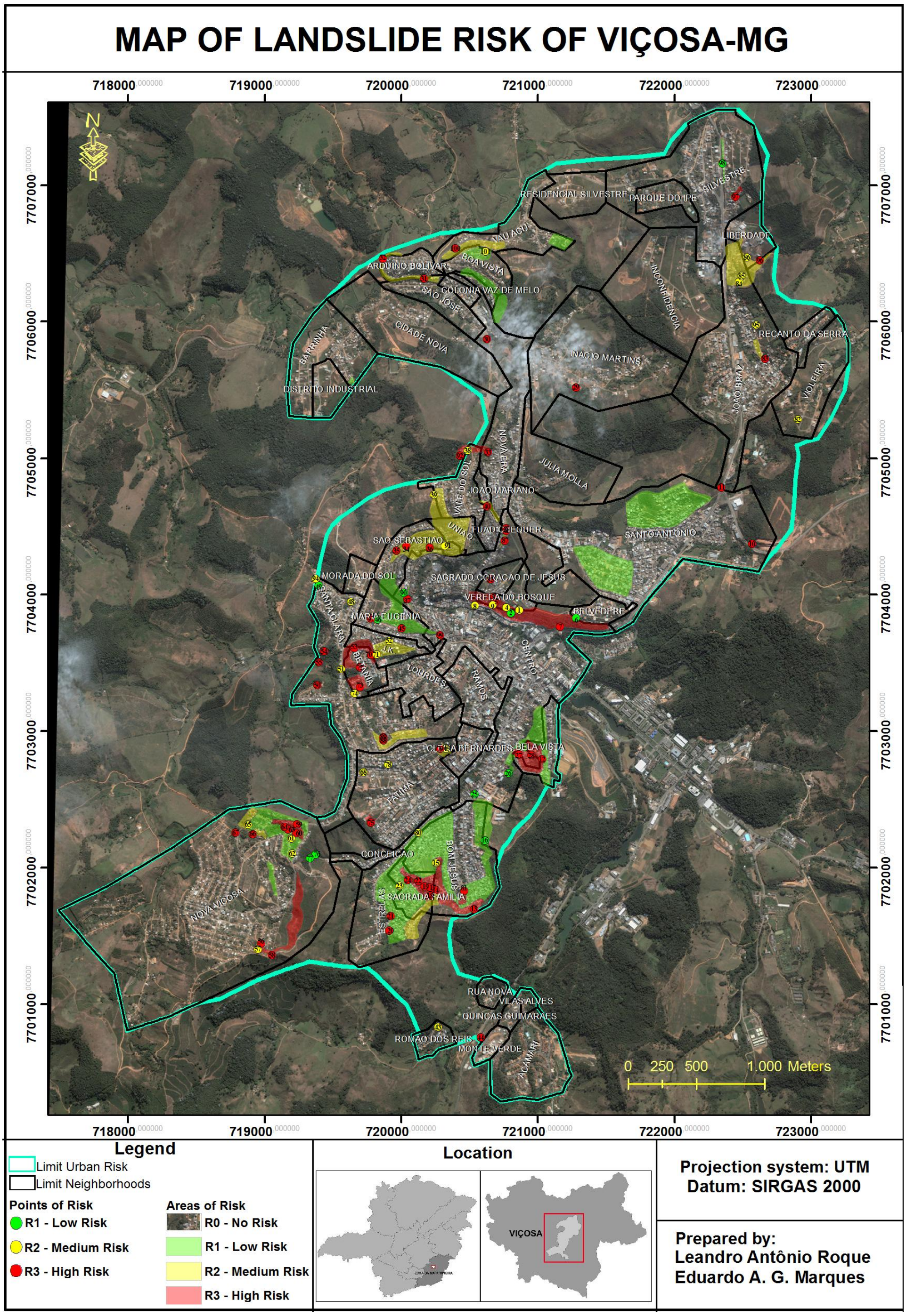

Figure 3: Landslide risk map of Viçosa urban area.

A preliminary risk characterization of Viçosa urban area was presented by Vieira (2000). The author has mapped 63 risk points for the same study area of the present work. This data was used to make a comparison between the results found in 2000 and the ones from the present study, as they have used similar risk identification methods, especially for medium and high risk points. Table 5 shows that a total of 34 medium and high risk points where identified by Vieira (op. cit.) while in 2013, the present study has identified 90, a growth of more than 167%. These result shows that one of the main problem related to risk increase in Viçosa urban area is mainly related to the absence of a urban planning, as physical (slope, topography, etc.), geological and geotechnical conditions (declivity, geology, soil types, soil thickness and strength characteristic) are quite similar for all urban area. As Viçosa presents very steep hills on urban area, because usually these areas are commonly occupied by lowest income population, and as there is no public policies or technical standards to control and to direct public how to correctly occupy these areas; commonly the way people cut the slope and modify superficial and natural flow increases the risk of mass movements.

Risk Classes	2000	2013
Low (R1)	34	11
Medium (R2)	5	31
High (R3)	29	59
Total Number of Risk Points	63	101

Table 5: Comparison of results from 2000 (Vieira, 2000), and 2013 risk mapping in urban area of Viçosa.

Mapping mass movements risk presented on the present paper made possible the generation of a risk map (Figure 3) for the urban area of Viçosa. It must be highlighted, however, that the database generated in this study supports production of maps on scales of up to 1:10,000, since it is intended that the results of this study may be useful to Viçosa City Council as an urban planning tool.

Discusssion

For a more detailed discussion and to facilitate the display of data, results were divided into more larger-scale maps, in order to facilitate the discussion for each district, as here are different risk classes among them. On this present paper, because of size restrictions, the authors have chosen the ones that better represent standard geological-geotechnical risk situations observed for all Viçosa urban area occupation.

Nova Viçosa District

Nova Viçosa district, together with Centro districts, are the regions that has shown the highest number of risk points (fourteen) and risk areas (six). This neighborhood is completely inserted in a single watershed (catchment area) and its surroundings present hills with slope greater than 30%.

The points number 56, 58, 59, 60, 63, 64, 66, 67, classified as high risk, are well-marked by the presence of the following characteristics that lead to this risk level:

- Low constructive standard houses, generally located on high slope terrains;
- Slope cuts with high declivity and height;
- Natural or artificial drainage system damaged or non-existent;
- Exposed soil; and
- Presence of landslides scars and/or erosional features.

The photos presented in Figure 4 (point 58 and 59, respectively) shows, as an example, access roads without any pavement and drainage system, on the top of a high slope, with houses of low constructive pattern, with exposed soil and presence of banana trees that are well known for its overloading effects due to accumulation of water in their roots. This set of factors generates instability on the ground and high risk of sliding during rain periods. High-risk areas require structural actions with greater urgency. It is suggested that urban occupation does not establish in these high-risk areas.

Point 58

Point 59

Figure 4: Points 58 and 59, classified as high risk (roads located on top of a hilly slope without any pavement or drainage system).

On medium risk areas and on places located at points number 57, 61, 62 and 65, the main risk factors identified were modification of natural drainage conditions (cuts and embankments) and damages caused on the artificial drainage system, which was also undersized, but factors such as slope, presence of trash and debris on face/top of he slope, has also contributed to geological-geotechnical risk classification. It should be noted that if both preventive and corrective actions are not deployed on these areas they may have its risk rating elevated to high.

Points 76 and 77 and low-risk areas mapped in this sector are places where landslide trigger agents exert low influence. Although, occupation of these areas should be planned in such a way that the risk of mass movements in these areas would not be increased by disorderly occupation.

The map in Figure 5 shows the location of points and hazardous areas.

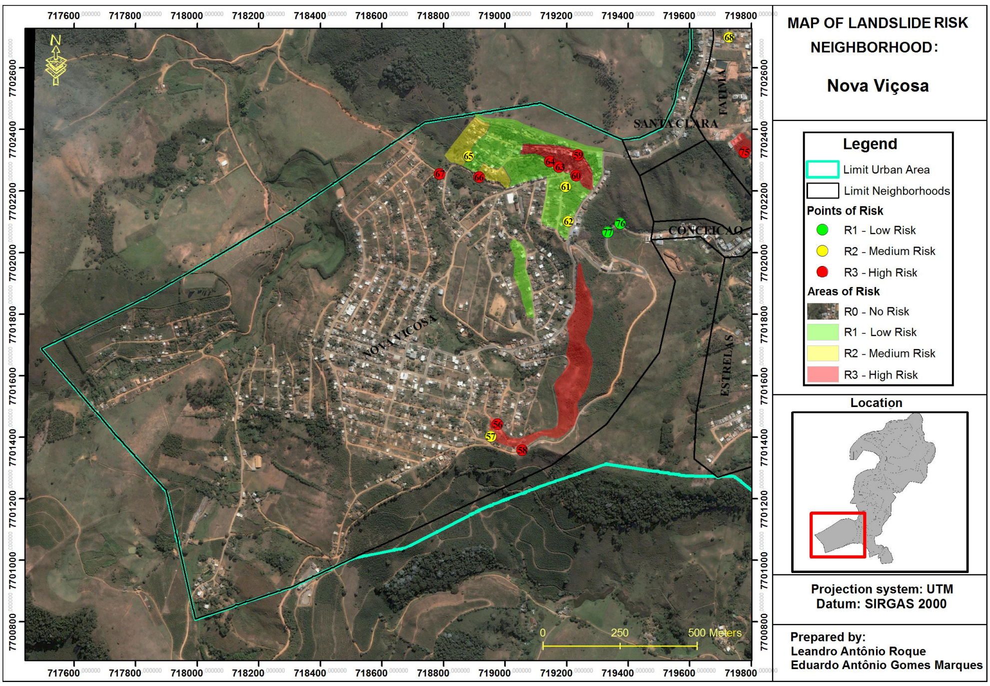

Figure 5: Landslide risk map of Nova Viçosa district.

Sagrada Família, Bom Jesus, Conceição, Fátima, Santa Clara, Centro and Bela Vista Districts

These neighborhoods, represented on Figure 6, highlight the vast, high-risk area located between the neighborhoods Estrelas and Bom Jesus, in which were identified several high-risk points (points number 13, 14, 17, 18, 19, 22, 24 and 81). The slope is greater than 35%, with the presence of low constructive pattern residences and several inadequate cuts and landfills.

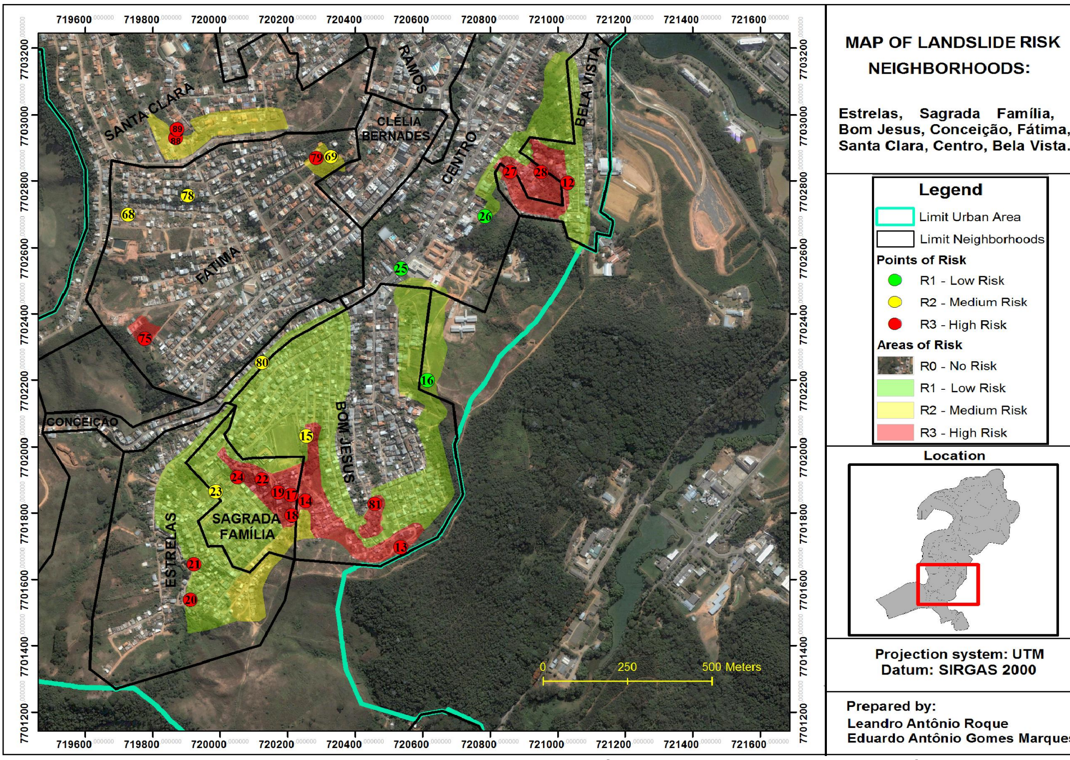

Figure 1: Landslide risk map of Estrelas, Sagrada Família, Bom Jesus, Conceição, Fátima, Santa Clara, Centro and Bela Vista districts.

High-risk points (20, 21, 27, 28 75, 79, 88, and 89) are points that exhibit slopes with high height and declivity, in which there have been landslides. For the high risk point, number 12 – Bela Vista district, the highest risk factor is related to a terrain located at the top of hill with slope greater than 40%, which is used as a irregular dump site by the community. The debris located on this site, associated with the slope of the hill, endangers the population of Rua São José, located on the bottom of the tank.

Delimitation of risk area existing in the vicinity of the points 12, 27 and 28 was based on the fact that most of the houses located in the Bela Vista district, especially those located at the top of the slope, and those built below street level, do not have sewage collection, which is simply released downwards.

Medium risk points (15, 23, 68, 69, 78, 80) are located in locations of higher declivity, with both natural and artificial drainage systems damaged. Recovering of these drainage systems is necessary to prevent landslides.

In low-risk points (16, 25 and 26) there were signs of erosion due to damage of the natural drainage systems and the absence of an artificial drainage one.

Pictures on Figure 7 presents images of the aspects described above.

Point 24 - High natural gradient slope

Point 75 - Cut slope with high declivity

Point18 - Undermining of contention wall

Point 17 - Dump disposal on top of a slope

Point 12 – Disposal of dump on top of a slope

Point 15 – Damaged drainage at the top of a slope

Figure 7: Examples of some of the existing aspects in the risk areas of Estrelas, Sagrada Família, Bom Jesus, Conceição, Fátima, Santa Clara, Centro and Bela Vista districts.

Santa Clara, Betânia, J.K, Centro, Maria Eugenia, União, Vale do Sol, Vereda do Bosque, São Sebastião, João Mariano, Fuad Chequer and Sagrado Coração de Jesus Districts

This set of neighborhoods represented in Figure 8 concentrates the largest number of risk points registered in the present study. From a total of 42 points of risk, 25 points were classified as high risk, 13 points were classified as medium risk and 4 points were classified as low-risk.

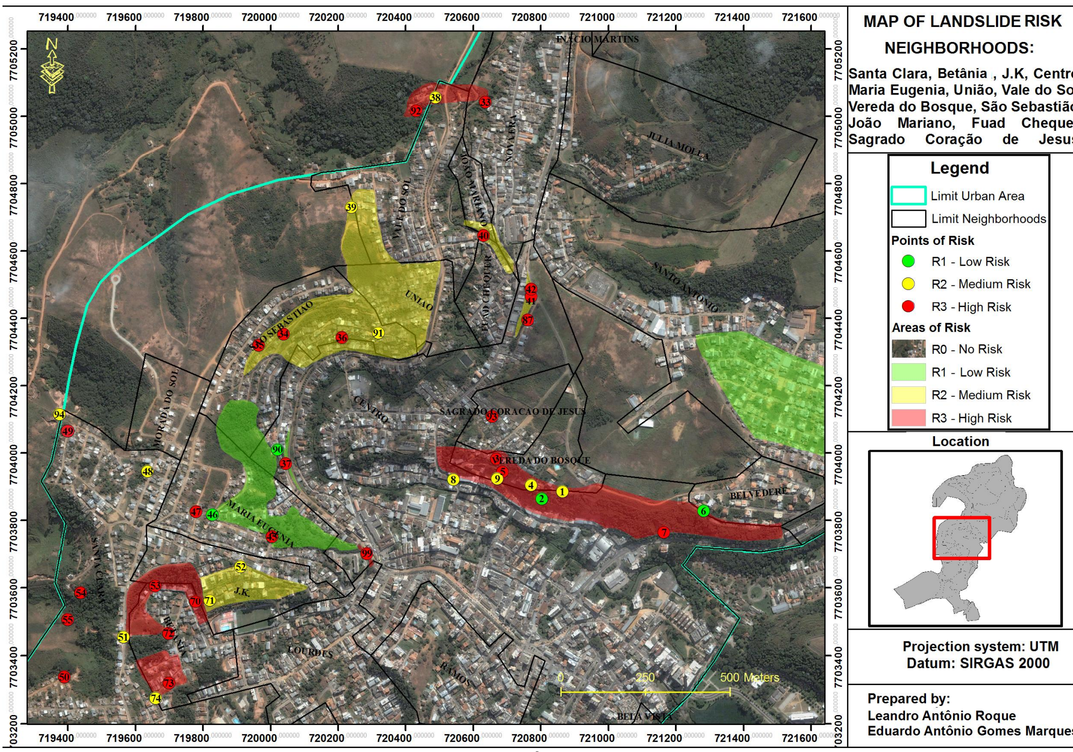

Figure 8: Landslide risk map of Santa Clara, Betânia, J.K, Centro, Maria Eugenia, União, Vale do Sol, Vereda do Bosque, São Sebastião, João Mariano, Fuad Chequer and Sagrado Coração de districts .

High-risk points number 3 and 5 presents scars of landslides occurred in January 2012, mainly due to the high slope of the terrain - more than 45%, to poor drainage and to buildings constructed to close to slope top. At point number 5 it is also observed, in addition to these factors, the presence of rubble that is played indiscriminately at the top of the slope. At points 7, 37 and 45 the high risk is mainly caused by deficiency in natural drainage and damage of artificial drainage system. In point 45 the lack of drainage is also responsible by erosion processes verified in this local.

The lack of drainage and paving of streets that are located at the top of the slope are common risk-generating situations observed in points 34, 47 and 53, while the high level of risk observed in paragraphs 35 and 93 is due to the presence of large amount of trash and debris.

Slope cuts with high declivity and/or height are main factors responsible for high landslide risk situations observed at points 36, 40, 42, 50, 54, 55, 70, 72, 87 and 99. In point 55 did not yet exist on the date of completion of the image, the set of popular houses located at the base of the slope on point 87. In point 40, in addition to the high cut slope, there are some rock blocks in slope face that lies in the back of the gas station located at Rua dos Passos. As there is a dense bamboo vegetation on this site, a large amount of water is retained on this slope, which acts as extra weight, increasing the risk of sliding.

The washout of the creek margin observed in point 92 provoked a great degree of subsidence near a residence, making high the risk of total collapse. At point 33, located on the same stream, excessive rains during January 2012 destroyed a drainage gallery and part of the railway line.

At medium risk points (1, 4, 8, 9, 38, 39, 40, 51, 52, 71, 74, 91 and 94) were observed landslides and erosion processes caused by a deficiency in the drainage system, whether natural or artificial, and preventative solutions must be taken to avoid any increase in the degree of risk of these sites.

Low risk points (2, 6, 46, 90) are places where risk factors have low influence. These sites, although, must be monitored, so as to avoid the emergence of risk factors.

In general, all areas of low risk occupation must be monitored to avoid triggers risk factors. In those places where there is vegetation occupation should be avoided, as its presence presence is ensuring the low risk of slipping.

On medium risk areas mapped in these neighborhoods, urban occupation must be done carefully and with previous planning, employing specific projects for each situation, avoiding mainly housing construction with low constructive standard.

High-risk areas delimited on these neighborhoods are locations in which the occupation must be avoided, and all existing buildings should promote measures to decrease the risk of landsliding, mainly those focused on slope cuts and drainage channels. If these works are not installed, there is a need to interdict several dwellings. Figure 9 presents some of the risk situations found in these sets of neighborhoods and described above.


Point 03 – Sliding on top of a slope


Point 49 - Cracks in home built on a landfill


Point 05 - Trash and debris launched on top of the slope


Point 53 - Street at the top of the slope without paving and drainage


Point 07 - Natural drainage damage system damaged causing landslides


Point 92 - Subsidence caused by margin erosion, on a creek

Point 33 - Gallery and rail road destroyed by floods

Point 99 – High declivity cut slope.

Figure 9: Examples of some of the existing aspects in the risk areas of Santa Clara, Betânia, J.K, Centro, Maria Eugenia, União, Vale do Sol, Vereda do Bosque, São Sebastião, João Mariano, Fuad Chequer and Sagrado Coração de Jesus.

Delimitation of areas of risk was based on the following main aspects: building constructive pattern, slope inclination, drainage conditions, presence of previous movements and type of ground vegetation. Some aspects were clue to the definition of risk zoning, as the use of the slope map and the high resolution satellite image.

Conclusion

The increase in the number of risk points registered between 2000 and 2013 is the result of accelerated unplanned urban sprawl of the Viçosa urban area through these last few years. This sprawl is mainly produced by a natural reason – steep hills and few flat stable areas to serve as human occupation; and a economic reason - as the interests of real estate and constructors agents, allied to a lack of a public policy unable to fulfill the laws of zoning and urban planning, is mainly focused on consolidation of central areas. This process, common to several Brazilian cities has lead to an increase in the number of inhabitants occupying risk areas, especially in the upper portions of the slopes and the top of hills and valleys, as lower lands near the central area are already saturated.

The main mass movements processes observed in the studied area are shallow landslides and erosion processes related to the occupation of lands with slopes exceeding 40%, in which natural drainage is damaged and constructed drainage is nonexistent or insufficient. Also, a small number of occurrences related to erosion of riparian margins were mapped.

The main objectives of the present has been achieved even with the use of a six years old satellite image. The application of datasheet registration forms allowed the construction of a digital database that can be easily used by municipal authorities and allowed the adjustment of the limits risk areas to the current reality of the urban area through a validation field process.

The methodology proposed by the Brazilian Ministry of Cities and adapted in this study secured a agile, easy to perform and low cost mapping. The database created can be used in execution of works and mitigating risk interventions identified in the areas of high and medium risk, or preventive for low-risk areas.

Acknowledgments

Authors would like to thanks CAPES for the financial support for this study, and to Departamento de Engenharia Civil, Universidade Federal de Viçosa for technical support.

References

BRAZIL. Ministério das Cidades e Instituto de Pesquisas Tecnológicas (IPT). Mapeamento de risco em encostas e margens de rios. Brasília, 2007. Available at:http://www.cidades.gov.br/. Access in: March, 12th, 2012.

CARVALHO, C. S. & GALVÃO T. (eds.) Prevençãode risco de deslizamentos em Encostas: Guia para elaboração de políticas municipais. Ed. Gráfica Brasil. Brasília, Ministério das Cidades; Cities Alliance; 2006, 111f.

COSTA, F., Dinâmica dos processos erosivos atuantes em três encostas no município de Viçosa-MG: Uma análise. 2006. 62f. Monografia - Universidade Federal de Viçosa, Viçosa, MG, 2006.

GOMES, G. J. C. et al, Uso de técnicas de geoprocessamento no zoneamento de áreas de risco de escorregamento em Ouro Preto – MG. Anais XIII Simpósio Brasileiro de Sensoriamento Remoto, Florianópolis, Brasil, 21-26 abril 2007, INPE, p. 2681-2688.

Jornal Folha da Mata. Viçosa: 1985 a 2012. Consultado em 07 a 11/01/2013.

PORTES, R. C. Determinação da fragilidade ambiental da bacia hidrográfica do Ribeirão São Bartolomeu, Viçosa – MG através de geoprocessamento e análise multicritério. 2008. 58f. Monografia - Universidade Federal de Viçosa, Viçosa - MG, 2008.

ROQUE, L. A. Áreas de risco geológico-geotécnico associadas a movimentos de massa no núcleo urbano de Viçosa-MG. Viçosa: UFV, 2013. 120f. Dissertação (Mestrado em Engenharia Civil) – Programa de Pós-Graduação em Engenharia Civil, Universidade Federal de Viçosa, Viçosa.

TOMINAGA, L. K. Avaliação de metodologia de análise de risco de escorregamento: Aplicação de um ensaio em Ubatuba – SP. São Paulo: USP, 2007, 220f., Tese (Doutorado em Geografia Física) – Universidade de São Paulo, 2007.

VIÇOSA. Prefeitura Municipal de Viçosa. Viçosa digital cartographic database. Digital files. 2009.

VIEIRA, V. Caracterização preliminar do risco geológico da área urbana de Viçosa - MG. Viçosa: UFV, 2000. 92f. Dissertação (Mestrado em Engenharia Civil) – Programa de Pós-Graduação em Engenharia Civil, Universidade Federal de Viçosa, Viçosa.