Soil Landslide Risk Charts of the Urban Area of Ponte Nova-MG

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Abstract. This paper addresses the construction of the soil landslide risk charts of the urban area of the city of Ponte Nova, Minas Gerais state, Brazil. A systematic survey of office and field data was considered to elaborate thematic risk charts (lithostructural, geological-geotechnical, slope and soil use and occupation), which when crossed permitted the construction of current and potential soil landslide risk charts. This study endeavored to supply a diagnosis of the risk situations in the urban area of Ponte Nova, to help in the adoption of future short, mid and long term political and structural measures to reduce, correct and prevent catastrophic events in areas associated to urban occupation.
Key words: risk chart, landslides, Ponte Nova, thematic risk charts.

1. Introduction

The phenomenon of hillside and slope instabilities frequently causes accidents whose damage can be greatly increased when they occur in urbanized areas. Modifications in topography, hydrological and hydrogeological conditions and geomorphological processes, especially those that result from urbanization of new areas, are often the main causes of these phenomena.

Regarding the result of anthropogenic action in urban areas, generally with a high occupation density of the flat areas or those with little slope, the occurrence of landslides is due to the fact that urbanization expands to the steep hillsides that are geotechnically less favorable for use. This is a common problem in the underdeveloped and developing countries, where disorderly growth and occupation of geotechnically unsuitable areas, especially by the low income population, has created an increasing number of problems of hillside instabilities.

Considering the importance of cartography of landslide risks for planning of the use and occupation of open areas, the present paper is concerned with the elaboration of soil landslide risk charts for the city of Ponte Nova based on a study by Natali (1999).

2. Information on the Study Area

2.1. Geographic location

The study area is the urban portion of Ponte Nova, located in Zona da Mata, southeast of Minas Gerais State, covering approximately 9 km^2. The area lies between the UTM 7740/7743 and 716/721.5 coordinates and the 20°25'00" latitude south and 42°54'40" longitude west geographic coordinates.

Ponte Nova is bounded by the municipalities of Rio Doce, Santa Cruz do Escalvado, Urucânia, Guaraciaba, Teixeiras, Amparo do Serra, Jequeri, Barra Longa, Acaiaca and Oratórios and has, according to the IBGE (2000), a resident population of 48.997 inhabitants in the urban area.

2.2. Physiographic aspects

The Cwa and Aw climatic types occur in the Zona da Mata region (microregion of the Ponte Nova Forest) according to the Köppen climate classification. The Cwa type, humid with hot summers, is predominant in the higher zones and is characterized by a short dry season, mean annual temperature between 19.5 °C and 21.8 °C and annual rainfall between 1,100 mm and 1,400 mm. The Aw climate,

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tropical wet and dry, dominates the lower parts of the area, with mean annual temperature between 21.4 °C and 24.7 °C, well-defined seasons and rainfall concentrated from October to March.

The regional hydrographic network belongs to the Doce River Basin, where the main rivers are the Piranga and the Casca, that drain, respectively, the East and West portions of the region from south to north, forming a drainage network characterized by lithostructural control.

The municipality of Ponte Nova is cut mainly by the Piranga River that rises in the Serra da Mantiqueira Mountains and is called the Doce River after the confluence with the Carmo River, close to the city of Rio Doce. The Vau-Açu stream and the Manso, Pedreira and Passa Cinco creeks are the main affluents of the Piranga River within the research area.

The vegetation of the region is characterized by fragments of Atlantic Rain Forest, more usually found on hill tops. The current floral aspects reflect anthropogenic action on the natural environment, and one can refer to a landscape combined of pastures and scrub, fragments of native forest but pastures predominate significantly.

The study region is characterized geomorphologically by low round-topped hills shaped like half oranges, a typical structure of granite-gneiss landscapes, gentle hillsides and open valleys. The morphological features of the area shows a strong influence of the geological variables and one can refer to the lithology, stratification and faults.

The urban area studied of Ponte Nova lies within the limits of a semi open valley, concentrated in the lower parts, on the banks of the Piranga River, and spreads progressively to the hillsides. The region is divided into four dominions, characterized as follows: (i) orthogneiss of the Mantiqueira complex; (ii) paragneiss of the São Sebastião do Soberbo metamorphic suite; (iii) metavolcanic and sedimentary sequence of the Dom Silvério group; (iv) high degree rocks from the Juiz de Fora complex.

3. Methodology

3.1. General considerations

In the present study, the whole urban sector of Ponte Nova was defined as an area of interest for the elaboration of the landslide risk chart. A data set was used regarding: (i) 18 topographic bases; (ii) 17 pairs of aerial photographs on the scale of 1:8,000; (iii) orthophotographs on the 1:10,000 scale as a base for the geological field mapping; and (iv) the IDRISI software version 2 for WINDOWS to generate maps in the "raster" format.

3.2. Preliminary survey of the area and past landslides description

The urbanized neighborhoods and those undergoing urbanization in Ponte Nova were surveyed using the orthophotograph on the 1:10,000 scale, mainly those located in the hillside sectors. The set of critical points was located on the base map (orthophotograph) for the geological-geotechnical assessment in the investigation phase. The types of characteristics landslides of the area including mainly soil/saprolite and block falls were identified using this preliminary field survey, the data collected at the inventory stage and with the help of aerial photographic analysis performed at the Minas Gerais Electrical Company (CEMIG) Office in Ponte Nova.

3.3. Field investigation

In this phase, most of the resources necessary to elaborate the chart of landslide risks for Ponte Nova were assembled and the conditioners and influencing attributes on the landslide processes were defined and the systematic field surveys carried out.

3.3.1. Conditioner and attribute definition

To draw up the chart of landslide risks, the following conditioners/attributes were investigated, considering the type of landslides defined in the study area, as follows:

• Geological-geotechnical compartments: the lithology, main geological structures (stratification, fault, fracture), other features of interest, such as landslide scars, rock outcrops and existing rock outcrops and their influences on the landslide processes in the study area;

• Slope: the critical slope intervals were considered for triggering landslide processes, that were analyzed by the chart of slope risks using the SIG/IDRISI software;

• Soil use and occupation: the form of use and occupation of the urban soil was taken into account, the population flow of each neighborhood located on the hillsides, construction types, cut slopes inclinations for house and road constructions, basic infrastructure (rainwater drainage system and street surfacing) and their effects on landslides and correlated processes;

• Vegetation: the existence of vegetation foci was verified on the urbanized hillsides and their relationships with the mass gravitational movement processes;

• Rainfall: rainfall data from January 1960 to February 1998 were analyzed to obtain correlations with the past landslides.

3.3.2. Systematic field surveys

The systematic field surveys included two main and parallel activities, namely: (i) lithostructural mapping; and (ii) landslide recording and the description of natural and cut slopes. The studies were carried out in a period of approximately 60 days, with logistical support from the Ponte Nova City hall.

The lithostructure was mapped using as base map two orthophotographs on the 1:10,000 scale from 1987, supplied by CEMIG. The mapping study involved cartography and description of the lithology and geological structures that presented direct relationships with the landslides and correlated processes, such as stratification, faults and fractures. The landslides were recorded and the natural and cut slope inclinations were described parallel to the development of the lithostructural mapping.

3.4. Photographic interpretation and cartography

This stage was developed by interpreting aerial photographs and orthophotographs that enabled observation of standard features characteristic of landslides and the local geology. Pairs of aerial photographs on the 1:8,000 scale and two orthophotographs on the 1:10,000 scale covering all the urban area of Ponte Nova were used throughout the study.

The cartography studies were carried out shortly after finishing the field surveys, using photographic interpretation. Pre-existing maps and data were used in this task, along with data collected in the field phase and aerial photographic interpretation. The required thematic charts were drawn up for the elaboration of the final chart of landslide risks. The main maps elaborated were:

- Lithostructural, developed from systematic field surveys and data collected during photo interpretation. They were on the 1:10.00 scale, based on two orthophotographs on the 1:10,000 scale dated 1987 that was supplied by CEMIG. This map contained the lithology and main structural features of the area including their atitudes;
- Geological-geotechnical, prepared on the 1:10,000 scale and containing the main parameters of the study area, such as: lithology, structural features, rock outcrops, landslide scars, slopes and points of water springs. This information was collected in field surveys, photographic interpretations on the 1:8,000 scale and in orthophotographs on the 1:10,000 scale;
- Slope chart, elaborated for the Ponte Nova urban area based on the classification system used by IPT (1991). This chart was developed from a planialtimetric base using the IDRISI software version 2;
- Soil use and occupation chart, elaborated on 2,000 scale from the planialtimetric base, orthophotographs on the 1:10,000 scale and aerial photographs on 1:8,000 scale.

3.5. Use of digital cartography techniques and SIG

At this stage, the charts and thematic maps generated in the study were transformed to the digital format, using the AutoCAD R14 program for data application of the SIG techniques by the IDRISI software version 2 for Windows.

4. Results

4.1. Systematic field surveys

Tables 1 and 2 show the results of the field surveys, complemented by the interpretation of the aerial photographs and orthophotograph. Table 1 shows the position of the visited cut slopes, the cut slopes that presented instabilities (superficial or deep slides and/or slide scars), and theirs respective slope inclinations. Table 2 summarizes the situation of urban occupation, vegetation and drainage in the neighborhoods.

Regarding urban occupation, in Table 2 the term orderly was used to designate the neighborhoods that presented basic infrastructure, such as paved streets and electrical cable network, rainwater discharge network, sewage network, and the term disorderly was used to categorize the

Table 1 - Inclinations of the visited cut slopes and of the unstable slopes.

Neighborhood	Inclination of the visited cut slopes				Inclination of the unstable slopes			
	$15° < \phi \leq 45°$	$45° < \phi \leq 60°$	$60° < \phi \leq 75°$	$75° < \phi \leq 90°$	$15° < \phi \leq 45°$	$45° < \phi \leq 60°$	$60° < \phi \leq 75°$	$75° < \phi \leq 90°$
Tijuco				1				1
Guarapiranga	1	1	1	4		1	1	3
N.S. Auxiliadora				1				1
Vale Verde	1				1			
Santo Antônio	1			3	1			2
Triângulo				3				3
Triângulo Novo	1			2				1
CDI				2				
Vila Alvarenga			1	2				
S.C. de Jesus			1	8			1	3
São Geraldo				1				1
Esplanada			1	2			1	

Table 1 (cont.)

Neighborhood	Inclination of the visited cut slopes				Inclination of the unstable slopes			
	15° < ϕ ≤ 45°	45° < ϕ ≤ 60°	60° < ϕ ≤ 75°	75° < ϕ ≤ 90°	15° < ϕ ≤ 45°	45° < ϕ ≤ 60°	60° < ϕ ≤ 75°	75° < ϕ ≤ 90°
Vila Pachequinho				1				
Copacabana				2				1
Centro			1	4			1	3
10 de Maio				1				1
Gavetão			2	3				3
Vila Oliveira				4				2
Cidade Nova				1				
Fátima				3				1
São Pedro				5				
Novo Horizonte				1				
Nova Almeida				1				
Palmeiras			1	1				1
Raza			1	2				1
Lot. Novo 1				1				
Lot. Novo 2				1				1
Paraíso			1					
Antônio Girundi				1				

Table 2 - Urban occupation, vegetation and drainage of Ponte Nova neighborhoods.

Neighborhood	Urban occupation	Vegetation		Drainage		
		Tree	Low	Natural	Superficial	Rain water collector system
Tijuco	Sparse (orderly)	Sparse	Sparse	Efficient	Deficient	Deficient
Guarapiranga	Dense (orderly)	Sparse	Sparse	Deficient	Deficient	Efficient
Auxiliadora	Medium (orderly)	Sparse	Medium	Deficient	Deficient	Efficient
Vale Verde	Médium (orderly)	Sparse	Sparse	Efficient	Deficient	Efficient
Santo Antônio	Dense (orderly to disorderly)	Sparse	Sparse	Deficient	Deficient	Efficient
Triângulo	Dense (orderly to disorderly)	Sparse	Sparse	Efficient	Deficient	Deficient
Triângulo Novo	Dense (orderly to disorderly)	Sparse	Sparse	Efficient	Deficient	Deficient
CDI	Sparse (orderly)	Sparse	Sparse	Efficient	Deficient	Deficient
Vila Alvarenga	Dense (desorderly)	Medium	Medium	Efficient	Deficient	Deficient
S. Coração de Jesus	Dense (orderly to disorderly)	Sparse	Sparse	Efficient	Deficient	Deficient
São Geraldo	Médium (orderly to desorderly)	Sparse	Sparse	Deficient	Deficient	Deficient
Esplanada	Dense (orderly)	Sparse	Sparse	Deficient	Deficient	Deficient
Vila Pachequinho	Medium (desorderly)	Medium	Medium	Efficient	Deficient	Deficient
Copacabana	Médium (orderly)	Sparse	Medium	Efficient	Deficient	Deficient
Centro	Dense (orderly to desorderly)	Sparse	Inexistent	Efficient	Deficient	Efficient

Table 2 (cont.)

Neighborhood	Urban occupation	Vegetation		Drainage		
		Tree	Low	Natural	Superficial	Rain water collector system
10 de Maio	Dense (orderly to desorderly)	Sparse	Sparse	Deficient	Deficient	Efficient
Vila Oliveira	Medium (orderly to desorderly)	Sparse	Sparse	Efficient	Deficient	Deficient
Cidade Nova	Sparse (orderly to desorderly)	Sparse	Sparse	Efficient	Deficient	Deficient
Fátima	Dense (orderly to desorderly)	Sparse	Sparse	Efficient	Deficient	Deficient
São Pedro	Dense (orderly to desorderly)	Sparse	Sparse	Deficient	Deficient	Deficient
Novo Horizonte	Sparse (orderly to desorderly)	Sparse	Sparse	Efficient	Deficient	Deficient
Nova Almeida	Medium (orderly)	Sparse	Sparse	Deficient	Deficient	Deficient
Palmeiras	Dense (orderly)	Sparse	Inexistent	Deficient	Deficient	Deficient
Raza	Médium (orderly)	Medium	Médium	Efficient	Deficient	Deficient
Lot. Novo 1	Inexistent	Sparse	Médium	Deficient	Deficient	Deficient
Lot. Novo 2	Inexistent	Sparse	Medium	Efficient	Inexistent	Inexistent
Paraíso	Sparse (orderly)	Sparse	Sparse	Efficient	Deficient	Deficient
Antônio Girundi	Sparse	Sparse	Medium	Deficient	Inexistent	Deficient

neighborhoods that presented some deficiency in this sense. The classification of orderly and disorderly was also used to characterize the neighborhoods that showed simultaneous levels of efficiency and deficiency in their basic infrastructure.

It is pointed out that usually the neighborhoods with orderly to disorderly occupation were those that presented good initial planning, but as they grew and became populated, they extrapolated the limits of this planning, making them deficient in some aspects of the basic infrastructure. It can also be stated that most of these neighborhoods presented high population density, occupied most of the hillsides in Ponte Nova or began to develop in a part of the town and grew to the hillside, such as the neighborhoods of Santo Antônio, Triângulo, Triângulo Novo, Sagrado Coração de Jesus (Pacheco), São Geraldo, Centro, 10 de Maio, Vila Oliveira, Cidade Nova, Bairro de Fátima, São Pedro and Novo Horizonte.

The tree and scrub vegetation was sparse in almost all of the occupied area and was almost always represented by fruit, flowers and low growing plants typical of back yards, such as grasses. There was denser vegetation on the hillside tops, where remains of native vegetation combined with pasture were observed, but outside the occupied areas.

The urban perimeter of Ponte Nova was in a precarious situation regarding drainage structures, as understood from the data presented in Table 2. Throughout the study area there was a great deficiency in the drainage systems, whether natural, surface or rainwater. Consequently, the areas where there were no efficient drainage systems, a fact almost always caused by disorderly urban growth, was where the greatest risks of soil mass landslides were found. In these areas, after executing cuts and fills for civil engineering construction, the removed material was usually thrown down the hillside, without technical criteria, adding to the inconvenience of waste disposal and rubble resulting from improper occupation. In the rainy period, especially, these loose materials slid under the action of their own weight or by the reduction of their shear strength and destroy engineering works further down the hillsides.

4.2. Rainfall data

Rainfall data of the area under study collected at the Piranga rainfall station (code 02043010) and supplied by CEMIG are presented in Figs. 1, 2 and 3, encompassing the period 01/1960 to 12/1998.

Figure 1 shows that the period of greatest rainfall in the region studied was from October to March, and January was the month with the highest monthly average rainfall (55,99 mm), followed by December (49.6 mm) and in third place November (49.19 mm). The lowest rainfall measurements were recorded in June (7.52 mm), July (7.69 mm) and August (10.2 mm). It is known that water is usually considered the main generating agent of mass gravitational movements and that rain duration and frequency are the most important factors in triggering landslide processes. Corroborating this point of view, it was observed that the periods when the highest rainfall was recorded, that is, from October to March, as shown in Fig. 1, the highest indices of accidents related to landslides occurred.

Figure 2 depicts the maximum monthly rainfall from October 1996 to March 1997, which is the wet season in the

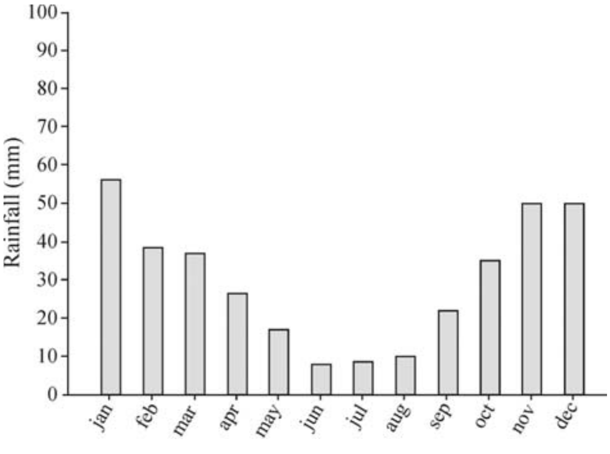

Figure 1 - Means of the maximum monthly rainfall in Ponte Nova from January 1960 to February 1998.

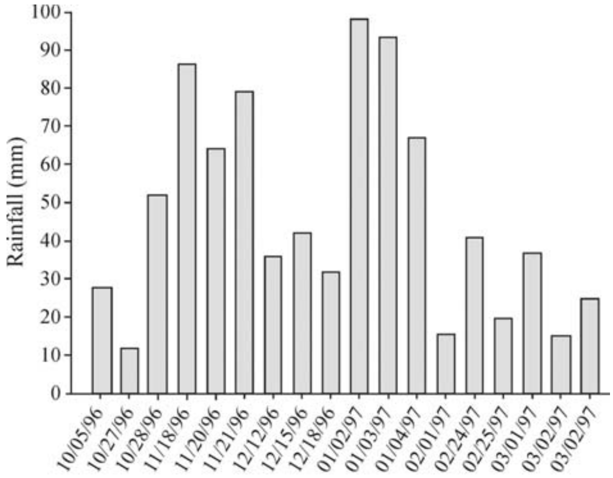

Figure 3 - Maximum rainfall of the three wettest days of each month in Ponte Nova from October 1996 to March 1997.

region. One of the highest monthly rainfalls of the last 20 years was observed in this period, reaching 98.3 mm rain in January.

It can be concluded from the analysis of the rainfall data presented in Figs. 2 and 3 that in the period from October 1996 to March 1997, January was the month that presented the highest rainfall rates and the values observed were among the greatest in recent times. It was at the start of this month (January 1997), between the days 01, 02 and 03 that there was one of the greatest floods of the Piranga River in the period analyzed. In this month there were also several landslides with housing destruction in Ponte Nova that were recorded by the Ponte Nova Civil Defense.

Figure 3 shows the maximum rainfall for the three wettest days of each month, also for the period from October 1996 to March 1997. This figure shows that on the days that it rained most, 02/01/97 with a rainfall of 98.3 mm; the next day, 3/01/97, with 91.3 mm and the days 18/1196 and 21/1/96, with daily rainfall rates of 86 mm and 79 mm, respectively.

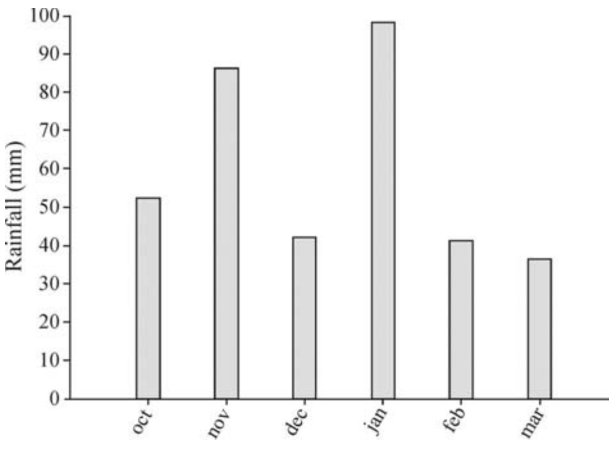

Figure 2 - Maximum daily rainfall of each month in Ponte Nova from October 1996 to March 1997.

4.3. Photographic interpretation and cartography

The photographic interpretation studies, based on the use of 17 pairs of aerial photographs on the 1:8.000 scale and two orthophotographs on the 1:10,000 scale, covered the urban area of the municipality of Ponte Nova. The photographic interpretation served as support for the systematic field survey, when the geological, lithostructural, soil use and occupation maps were made. The cartography studies resulted in the following maps and risk charts:

- Lithostructural map: this map, Fig. 4, contains the lithology and the main structural features and their attitudes in the study area. The whole area of residual altered gneiss soil was mapped and at some distinct points, gneiss outcrops were observed. An outcrop of basic rock (amphibolite) was also mapped and some recent formations, mainly in islands formed in the Piranga river bed. The gneiss stratification was outstanding among the structural features observed in the area, with angles between 5° and 30° but no preferential orientation in function of the intense deformation of the gneiss in this region;
- Geological-geotechnical map: this map, Fig. 5, shows the lithology, rock outcrops, landslide scars, water spring points, and identified erosion foci. These parameters were determined by field surveys and photographic interpretation studies. The landslide scars are highlighted in this map that occurred in the mapped area, mainly on the disorderly occupied hillsides. It is also of interest to observe the points of water springs and erosion foci;
- Slope chart: this chart is shown in Fig. 6, and the values of the percentages used are shown in Table 3, according to the classification criteria adopted by IPT (1991). It is emphasized that in function

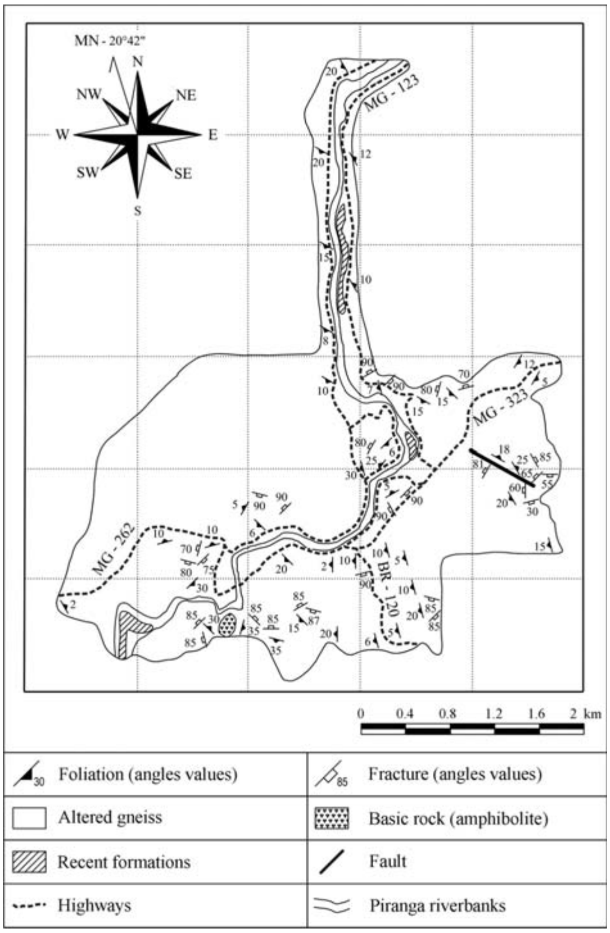

Figure 4 - Lithostructural map of the urban area of Ponte Nova.

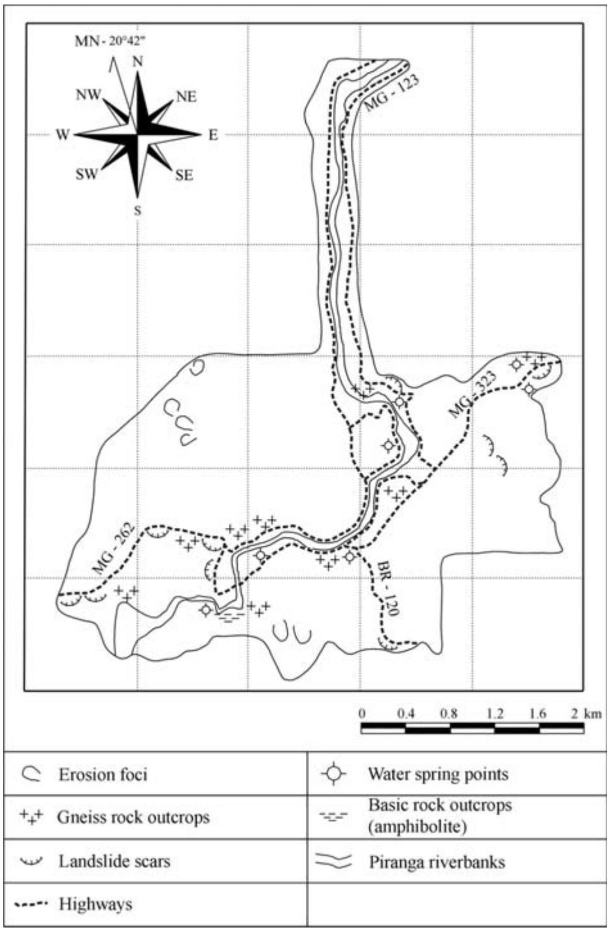

Figure 5 - Geological-geotechnical map of the urban area of Ponte Nova.

Table 3 - Slope intervals adopted, in percentage (IPT, 1991).

Interval	Significance of the limits
0 to 15%	15%: maximum slope tolerated for vehicle circulation
15 to 30%	30%: maximum slope permitted by law for hillside occupation without special planning
30 to 50%	50%: technically recommended slope limit for hillside occupation

of the characteristics of the terrain to be occupied, the slope contours may suffer alterations, decreasing the limit value by 50% for smaller contours according to the geotechnical study of the area. Technically, it is emphasized that areas with more than 50% slope can also be occupied, providing there are geotechnical solutions available;

- Soil use and occupation chart: this chart, Fig. 7, shows the types of characteristic occupation of the area studied. Four types of occupation were mapped, considering mainly the population flow of each neighborhood analyzed as follows: dense occupation, medium occupation, sparse occupation and nonexistent occupation. Of these four, the areas of dense occupation make up most of the city of Ponte Nova and presented the greatest concentration of landslides. The nonexistent occupation was characterized by contours within the urban area that have not yet been used by the population. In these locations, the vegetation was in the form of pastures, landslide occurrence was not observed and a direct relationship was inferred between anthropological action and susceptibility to landslides.

4.4. Current and potential soil landslide charts of the urban area of Ponte Nova

By crossing the thematic maps developed in the present study, following the suggestion by Cerri (1990), two soil landslide risk charts were obtained for the urban area of Ponte Nova, considering the current and the potential risks. Figures 8 and 9 show both the maps, elaborated on the

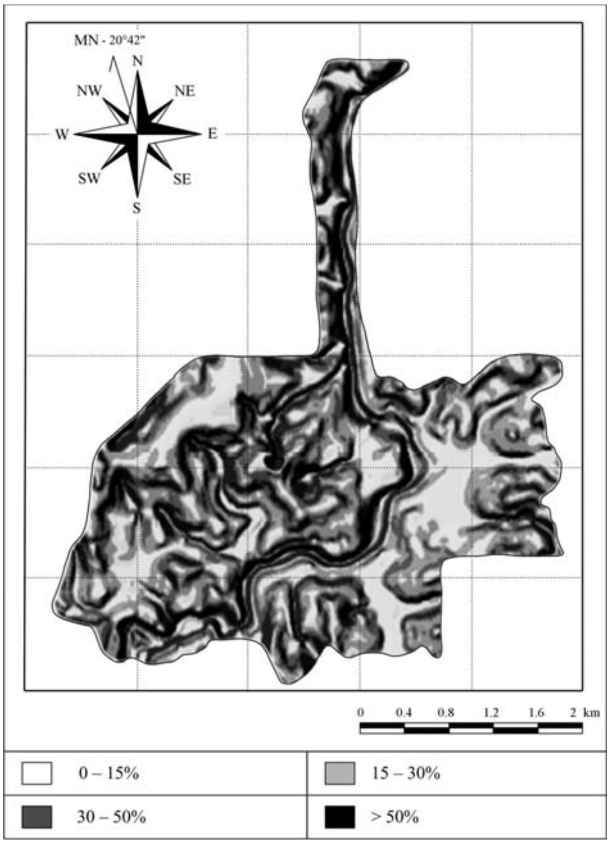

Figure 6 - Slope map of the urban area of Ponte Nova.

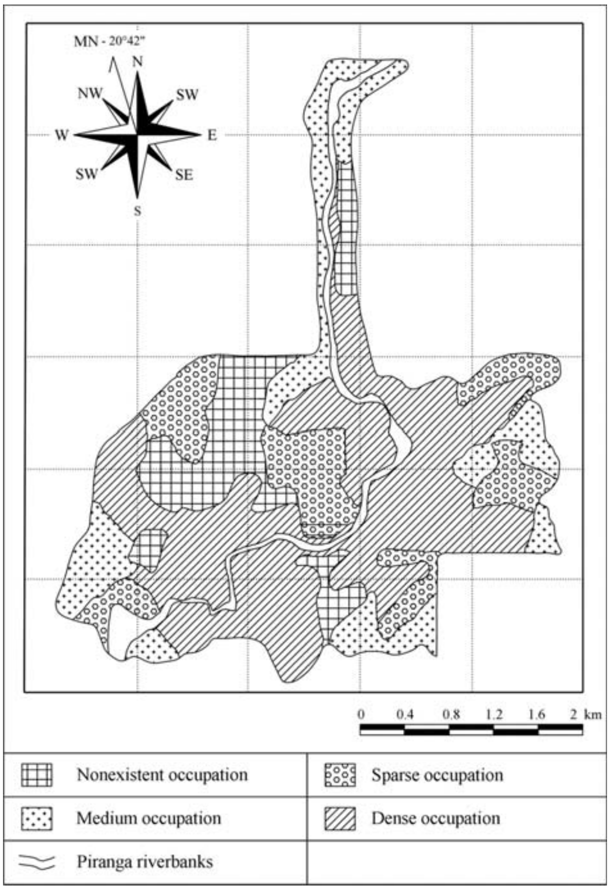

Figure 7 - Soil use and occupation chart of the urban area of Ponte Nova.

1:10,000 scale that have keys showing risk areas, their characteristics and recommendations for use and occupation, subdivided for the current risk and the potential risk situations. The use of the term *landslide risk* refers to the areas that may suffer movement and/or mass soil detachment.

It is emphasized that when elaborating the charts of landslide risks for the urban area of Ponte Nova a risk analysis was adopted where the classes and degrees of risk resulted from the qualitative assessment of the risk situations identified, conjugating the areas susceptible to landslides and possible social and economic damage. Several parameters were considered for the identification of the risk situations, notably vegetation, monthly and daily rainfall rates for the rainy season, anthropogenic action and especially slope inclination.

Four degrees of risk were adopted in the landslide risk classification, namely inexistent, low, medium and high. These degrees of risks were used to determine the zones with real or potential risk (susceptibility). It is pointed out that the use of this subdivision of risks aimed to establish, within the study region, areas that should receive immediate action (current risk) or planning (potential risk) from public authorities. Thus the different degrees of risk have the function of helping public administration in Ponte Nova in prioritizing these structural and nonstructural actions to be taken in the future.

It is pointed out, that in the study area the landslides occurred most frequently in young residual pink colored gneiss soil and less frequently in the soil with an overlay of red sand-clay colluvium. It was observed these landslides followed predominantly a circular rupture patter and were mostly induced by anthropogenic intervention combined with periods of heavy rainfall. It was detected that all the landslide scars analyzed and mapped were related to the occurrence of cut slopes without technical criteria, with unsuitable height and geometry and no superficial drainage structures. Furthermore, based on the analysis of the aerial photographs and field visits, landslides were not identified in the natural hillsides within the slope contours reported in the slope map presented in Fig. 6.

5. Conclusions

This is study endeavored to present a basic diagnosis of the risk situations in the urban area of the city of Ponte Nova, Ponte Nova, Minas Gerais state, Brazil, by establishing a landslide risk chart to (i) supply technical elements to help in aspects pertaining to urban planning of the city and

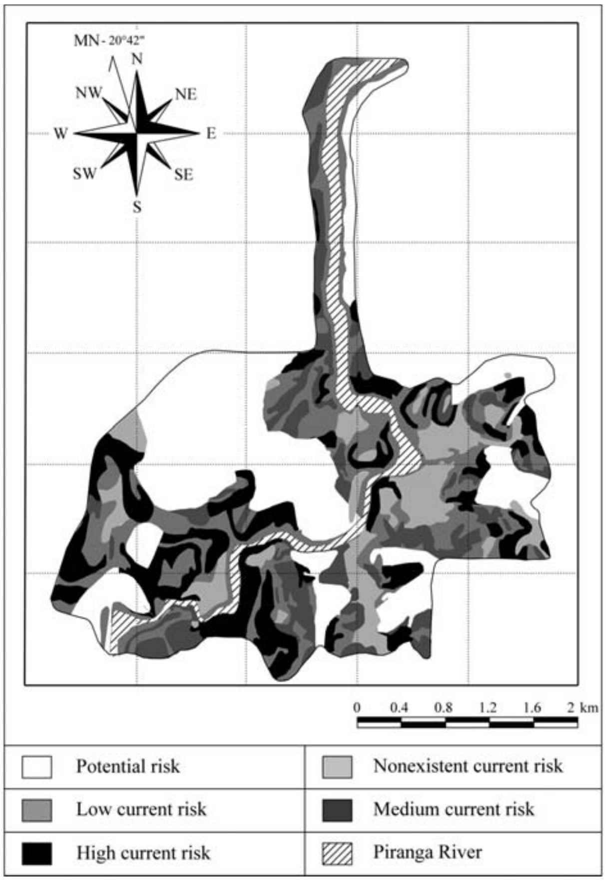

Figure 8 - Current soil landslide risk chart of the urban area of Ponte Nova.

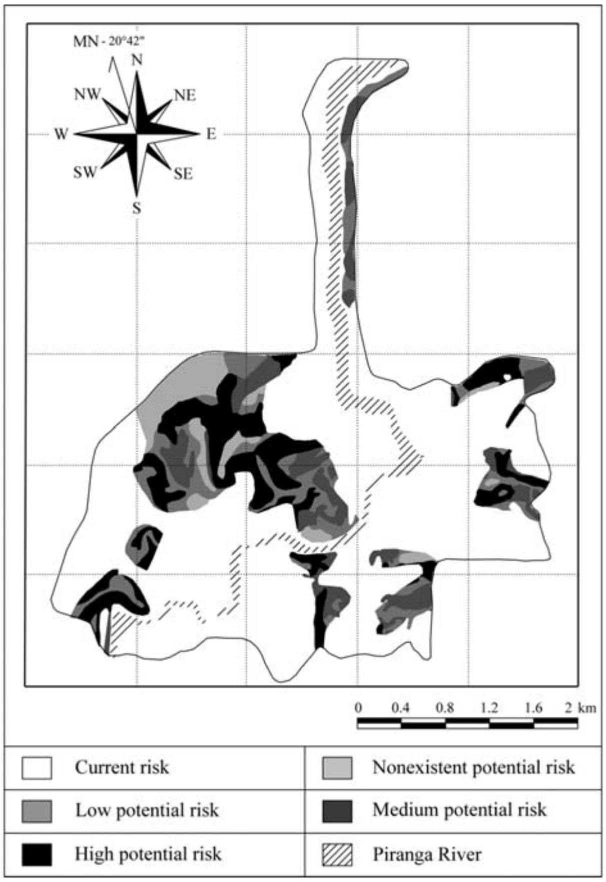

Figure 9 - Potential soil landslide risk chart of the urban area of Ponte Nova.

soil use and occupation; and (ii) supply elements for the adoption of corrective measures and especially, medium and long term preventative measures by the municipal authorities.

Specifically regarding the chart of landslide risks, the key for Figs. 8 and 9 shows in detail the areas with greatest landslides problems (high-risk areas) that need special care and priority of execution of corrective or preventative measures.

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References

Cerri, L.E.S. (1990) Geotechnical chart: Contributions to a conception directed to Brazilian needs. Proc. 6th Brazilian Engineering Geology Congress, Salvador, v. 1, pp. 309-317 (in Portuguese).

IBGE (2000) 2000 Demographic Cense. Brazilian Institute of Geography and Statistic, Brasília. Available in the site: www.ibge.com.br. Access in April 20, 2000 (in Portuguese).

IPT (1991). Slope Use and Occupation Manual. Instituto de Pesquisas Tecnológicas, São Paulo, 25 pp. (in Portuguese).

Natali, P.P. (1999) Preliminary Slope Chart Risk for the Urban Area of Ponte Nova. M.Sc. Thesis, Universidade Federal de Viçosa, 112 pp. (in Portuguese).