A Preliminary Assessment of the Distribution and Consequences of Natural and Some Anthropogenic Hazards in Brazil

L.V. Zuquette, O.J. Pejon, R.E. Lima, M. Dantas-Ferreira, V. Guimarães

Abstract. This paper presents the results from a preliminary inventory of natural and man-made hazards and/or disasters in Brazil. The data were collected from previous studies, aerial photographs, satellite images and field studies. The data were obtained to evaluate the spatial distribution of natural and man-made hazards and disasters in different cities and states and to delimit the areas that have been the most affected during the last 50 years. A total of 28 different types of hazards/disasters were identified in Brazil; flooding, gravitational mass movements, continental and coastal erosion, silting and sinkholes are the more frequent, expensive, socially devastating and fatal types of hazards/disasters. Santa Catarina, São Paulo, Rio de Janeiro, Paraná, Pernambuco, Minas Gerais, Bahia, Rio Grande do Sul and Espirito Santo are the states most often affected by these hazards and disasters and thus experience the largest economic and social costs and the most casualties. Eight zones in which natural and anthropogenic hazards and associated disasters have occurred most frequently are described in this study. Among these, the coastal zone (zone 2) and mountainous regions in Eastern Brazil (zone 8) were found to have been intensely affected by hazards/disasters, with frequencies ranging from annual (*e.g.*, flooding) to once every five years (*e.g.*, high-magnitude gravitational mass movements). The greatest economic and social losses and the highest reported fatalities in Brazil have occurred in these two zones.

Keywords: natural and anthropogenic hazards, disasters, economic losses, Brazil.

1. Introduction

In recent decades, studies have focused on assessing natural and anthropogenic (*e.g.*, technologic, social, cultural and land use related) hazards and/or disasters and other types of environmental problems throughout the world to better understand the mechanism, predisposition and triggering factors to prevent social and economic losses (Zaruba & Mencl, 1969; Varnes, 1984; White & Haas, 1975; Bolt *et al.*, 1975; OAS, 1990; Alexander, 1993; Guzzetti, Cardinali & Reichenbach, 1994; Guzzetti, Stark & Salvati, 2005; Kovach, 1995; Brabb & Harrod, 1989; Alcántara-Ayala, 2002; Alcántara-Ayala, 2004; Korup, 2005; Guzzetti, Salvati & Stark, 2005; Dilley *et al.*, 2005; Yang *et al.*, 2005; Remondo *et al.*, 2005; Claessens *et al.*, 2007; Zhou, Wang, Wan & Jia, 2010; Balteanu *et al.*, 2010; Kirschbaum, 2010; Novelo-Casanova & Suárez, 2010; CNR/IRPI, 2010; Bonachea *et al.*, 2010; Van Den Eeckhaut & Hervás, 2011). In general, hazards are a consequence of natural processes (*e.g.*, geological, climatological and hydrological processes) and the interactions between land use and the environment (anthropogenic hazards). Damaging events that are related to hazards that generate human, social, environmental and economic losses are described as disasters (UNDRO 1984, 1991; Varnes, 1984). Glade & Crozier (2005) presented an interesting study that reports inventories of features of gravitational mass movements that occurred in several countries in Europe, Asia, South America, the South Pacific, North America and Africa. The Organization of American States (OAS, 1990) and the United Nations (UN) created organizations to advise countries on the problems resulting from hazardous events and to encourage the development of methodologies to forecast and mitigate these disasters.

Brazil does not experience volcanic events or high-magnitude earthquakes (> 7 on a Modified Mercalli Intensity scale), but other types of hazards and disasters have resulted in significant casualties and costly damages. In the last 50 years, several regions of Brazil have experienced natural processes, such as floods, gravitational mass movements, erosion, soil and water contamination and waste

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spillage due to the ruptures of tailing dams, sanitary landfills and pipelines. However, the general population of Brazil has no clear understanding of the nature of these hazards and their direct and indirect economic consequences. In addition, hazardous events are often not distinguished from common events in the technical and scientific literature. Furthermore, no technical guidelines have been developed to forecast and respond to the different hazards and to avoid and mitigate disasters that are very common in Brazil.

Since the 1990s, studies have been conducted in Brazil by universities and independent research institutes (for example, Zuquette *et al.*, 1992; Gramani, 2001; IPT, 1995; CPRM, 2010; Cruz, 1974; Zuquette *et al.*, 1994a,c; IPT, 1995; Carvalho, 1996; Amaral & Palmeiro, 1997; Dorsi *et al.*, 1997; Bonuccelli, 1999; Herrmann, 2001; Bacellar, Lacerda & Coelho Neto, 2004; Herrmann *et al.*, 2004; CPRM, 2006), but public institutions have paid little attention to these hazards because in Brazil, there are no governmental centers to forecast these events. Most efforts of the governmental centers are concentrated on responding to the problems that follow the disasters.

Often, such governmental efforts are focused on the control of social problems rather than on the importance of forecasting and preventing the hazards (for example, Carvalho & Galvão, 2006; CENACID, 2010; DRM-RJ, 2011; GEORIO, 2011; BRASIL, 2011). These works have been developed based on predominantly in social and economical aspects of the affected places on the other side the geological and geotechnical data are secondarily considered. However, damages that occur as a consequence of natural and anthropogenic hazards can result in social losses, deaths and long-term economic losses. The effective management of these hazards requires a significant investment in rehabilitation, hazard control and problem-solving methods.

According to the data that have been collected by governmental institutions since 2007, approximately 800 disasters were recorded in several different regions (CENACID, 2010; CPRM 2010; Brazil, 2011; Brazil, 2012). The damages from these disasters ranged from 5,000 USD to more than 1,000,000 USD. Since 2008, several different types of natural disasters have occurred repeatedly in Brazil. These disasters have strongly affected the states in the southern and southeastern regions of the country. EM-DAT (2012) considered Brazil to be one of the most affected countries. Recently, Brazil was named by the UNITED NATIONS (2012) as the 3rd most affected country in terms of natural hazards and/or disasters in the world.

According to the data from the UN/ISRD (2010), the frequency of natural disasters has been steadily increasing in the world as well as in Brazil. The number of major recorded occurrences in the world has ranged from 70 to more than 400 annually between 1975 and 2010 (Fig. 1). The data allow us to distinguish five distinct periods directly associated with the growth and concentration of the population worldwide and in Brazil. Following this trend since 1965, Brazil has experienced a continuously increasing number of recorded disasters, which has coincided with the growth and concentration of the population in urban areas. According to the International Red Cross, Brazil is the country that is most affected by disasters related to natural hazards in the Americas. Between 1994 and 2011, there were more than 10,000 deaths, but according to governmental information, in 2010 alone, approximately 8 million people were affected, and 1,500 died, mainly because of gravitational mass movements, floods, droughts and other smaller disasters. This increase in damages is due to both an increase in the number of hazards and the fact that a greater proportion of hazards have affected a significant number of people (more than 20,000,000), mainly because disasters have occurred in the most populated regions. Since 2007, more than 300 significant disasters (each characterized by economic and social costs greater than 500,000 USD and casualties) have occurred in Brazil. In the last five years, more than 5 billion USD have been spent to aid areas affected by disasters that had resulted from natural processes and/or environmental problems. However, a limited amount of money has been invested in the forecasting of such events, and in some cases, a portion of this small amount of money is lost in the public system.

Given the large numbers of hazards and disasters resulting from natural processes and human activities, we developed a basic inventory of hazards and disasters for

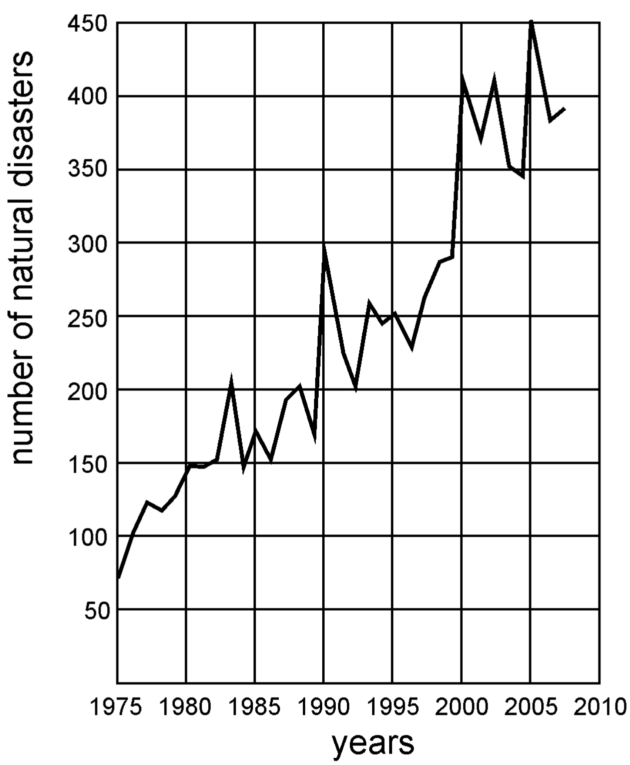

Figure 1 - The number of natural disasters worldwide between 1975 and 2010. From UN/ISRD (2010).

Brazil. The goal was to assess the distribution of hazards and disasters in each state and in the cities with the largest populations, which could be the most affected by such disasters. The records obtained would allow us to specify and define the most affected areas in Brazil and elaborate on the specific hazards and/or disasters threatening each state.

2. Challenges to Developing an Inventory of Natural and Man-Made Hazards and Disasters in Brazil

Studies of natural and man-made hazards are generally conducted after these hazards have led to consequent disasters. However, few studies aim to forecast the hazards and their associated risks. In general, the relevant studies can be classified into three groups. The first group includes studies that consider specific events; the goals of these studies are primarily related to the geological, geomorphologic and geotechnical characterization, design and installation of structural measures to prevent the problem from recurring in the future (for example, Pichler, 1957; Barata, 1969; Jones, 1973; Ploey & Cruz, 1979; Wolle, 1988; Elbachá, 1992; Cerri, 1993; Lacerda, 1997; Guimarães *et al.*, 2003; D'Orsi, Feijó & Paes, 2004, Déstro *et al.*, 2009). Approximately 75% of the studies conducted in Brazil are of this type. The second group is related to the discontinuous inventory of natural events. These studies emphasize susceptibility zoning, which uses engineering geological mapping at scales of less than 1:25,000. These maps are mainly based on qualitative data, but some studies have used quantitative geomorphological and rock substrate data and heuristic methods involving overlapping maps, with or without weighting (for example, Zuquette *et al.*, 1991; Zuquette *et al.*, 1994b; Augusto Filho, 1994; Amaral, 1996; Hach-Hach, 1998; Alheiros, 1998; Macedo, Costa & Salles, 1999; Herrmann, 2001; MINEROPAR, 2005; Amaral Junior, 2007; Dantas-Ferreira, 2008; Lollo, 2008). The third group is composed of hazard and risk mapping developed predominantly by universities at scales of less than 1:25,000 (rarely larger) and based primarily on semi-quantitative data (for example, Wolle & Carvalho, 1989; Ahrendt & Zuquette, 2003; Dias & Zuquette, 2004; Augusto Filho, 2004; Nunes Bandeira & Coutinho, 2008; Silva & Zuquette, 2010).

Several factors influence hazard studies in Brazil, such as the following:

- The large territorial extent of Brazil.
- The absence of governmental programs to develop continuous inventories. There are some data banks in various stages of development in the CPRM and in other organizations at the state level (for example, the MINEROPAR in Parana and the DRM in Rio de Janeiro), but these data banks exhibit serious problems involving data sources and registering predominantly landslides. A large part of the data contained in the different databases is the same as those obtained from surveys after the disasters.
- The lack of topographic maps at adequate scales for different parts of Brazil; the scales are generally less than 1:50,000, with a curve equidistance of greater than 20 m. In some regions, there are orthophotos at different scales and for different periods, but these photos are not linked to adequate topographic maps, which provide the fundamental basis for putting together information about natural and anthropogenic events.
- The lack of regular studies by governmental centers to map environmental factors at adequate scales (unconsolidated materials maps, rock substrate maps, drainage maps and continuous inventory maps, among others).
- The lack of regular surveys to obtain aerial photographs. High-resolution satellite images are expensive and have only been obtained for some specific areas where the economic losses were very high. Lower-resolution satellite images exist, but they are not fine enough to record the events. Brazil urgently needs a program to obtain continuous, high-resolution satellite images over extensive areas to create continuous inventories.
- Because of the climate in Brazil, most of the damaged and affected sites are quickly modified. Thus, identifying the affected areas becomes very difficult or even impossible.
- Most of the hazards are not reported. Only large disasters are registered.
- Records can sometimes be difficult to obtain because people are not accustomed to reporting small losses (less than 5,000 USD). However, in some regions, these losses are very common, especially when the events do not occur very rapidly, as they do with soil collapse and subsidence.

3. Materials and Methods

A central database of the natural and anthropogenic hazards and disasters does not exist in Brazil. Between 2007 and 2012, there was a large effort to compile the existing scattered information held by various organizations into a single database. The data search was conducted according to the following steps:

i The selection and preparation of basic data on the geology, relief and climatic conditions of Brazil to define and delimit the zones most affected by hazards and/or disasters. The geological data were collected based on the previous maps developed by CPRM (1971, 1983) and DNPM (1984) at scales of less than 1:1,000,000 and other maps that were produced for the states at scales between 1:500,000 and 1:1,000,000 (DAEE/UNESP, 1984; MINEROPAR, 2005; UNB, 2008; CPRM, 2007; IBGE, 2007). The relief data were collected from (Ab'Saber, 1964), FIBGE (1990), (Miranda & Coutinho, 2004), CPRM (2007) and IBGE (2007). The climatic map was prepared considering the annual variation in rainfall and temperature and the length of the dry season in different parts of Brazil obtained from (Nimer, 1989), INPE/CPTEC (2007) and IBGE (2007).

ii Data on the hazards and the associated economic losses were obtained from technical reports, theses (master's and doctorate) from the database of the most important universities of Brazil, magazines, state newspapers and other publications. These additional publications included the annals and proceedings of the national congresses and symposia supported by the Associação Brasileira de Geologia de Engenharia e Ambiental - Brazilian Association of Environmental and Engineering Geology (ABGE, 2007), the Associação Brasileira de Mecânica dos Solos (ABMS) - Brazilian Association of Soil Mechanics and proceedings of the international congresses of the International Association of Engineering Geology and Environment (IAEGE) and the International Society of Soil Mechanics and the Geotechnical Engineering (ISSMGE), as well as the proceedings from the International Congresses of Landslides. Most of these sources provided very localized and specific data. Natural and man-made hazards and disasters were assessed using a group of similar concepts of hazards, disasters, vulnerability and consequences proposed by (Varnes, 1984), UNDRO (1984), Crozier & Glade (2004), ISSMGE (2004) and (Fell *et al.*, 2008).

iii The geographical location of the recorded hazards and disasters. The geographical locations of the recorded hazards and disasters were only loosely provided, and the geographical coordinates were rarely given. To evaluate the distribution of the natural and man-made processes in Brazil, each data point needed to be placed on a map with all of the acquired information. Because of the vast extent of Brazil, the geographical position of each record was approximated based on an urban area or district, a natural slope, a valley of a natural drainage channel, or an escarpment.

iv Post-event aerial photographs and satellite images of the areas affected by hazards and disasters were analyzed to delimit the affected area and damage. However, these materials are scarce, and post-event analysis was only possible for a few areas.

v Fieldwork was conducted to assess great part of the areas that were greatly affected by hazards and disasters, to evaluate the reliability of the information in situ and to obtain new data on the events, such as the type, magnitude and size.

vi Using GIS and manual works, the spatial assessment of the data from the inventory was performed considering one or more of the following: the distribution of hazards and disasters in urban, forested and rural areas, the economic, social, environmental and humanitarian losses related to the disasters, the magnitudes and intensities of the natural events and the density and frequency of the natural and man-made events. For many of the recorded events, we could collect only one or two of these data.

vii The evaluation of the density (low - < $1/km^2$, moderate - 1 to $3/km^2$ and high - > $3/km^2$) and frequency (*e.g.*, monthly, annually or once every 5 years) of the natural and man-made hazards and disasters in the main urban areas was performed for the main urban areas in each state of Brazil.

viii An assessment of each state was conducted that considered the density and distribution of the various types of hazards and disasters. The magnitude of the economic, social, human and environmental losses was used to classify each state in terms of hazard/disaster into one of six levels (1 is the lowest and 6 is the highest) related to the attributes described above. These levels are described as follows: Level 1 - low-density (< $1/km^2$), small affected areas (< 10 km^2) associated with minor economic losses (< 100,000 USD); Level 2 - low to moderate-density, small affected areas associated with moderate economic losses (100,000 to 500,000 USD); Level 3 - low to moderate-density, medium-sized affected areas (10 to 100 km^2) associated with moderate economic and social losses; Level 4 - moderate-density (1 to $3/km^2$), medium-sized to large affected areas associated with moderate economic, social and environmental losses; Level 5 - moderate and high-density, large affected areas (> 100 km^2) associated with moderate economic, social, human and environmental losses; and Level 6 - high-density (> $3/km^2$), large affected areas associated with high economic, social, human and environmental losses (> 500,000 USD).

ix The most severely affected zones were defined based on the type of hazard and density of disasters considering the frequency and intensity associated with the human, economic and social losses, which were related to the geological, geomorphological and climatic aspects. The zones were displayed on a map of Brazil along with the main drainage channels to facilitate the delimitation of the zonal boundaries. After delimitation of the zones, a description of the relief, geology, and climatic conditions associated with the economic, social, environmental and human losses were formulated. The steps developed to delimit the zones were as follows: the evaluation of the density distribution of the hazards and disasters in the states, the analysis of the density distribution within the geological units based on the lithology, the identification of the most affected areas based on the geological units experiencing a high density of events, for the zones mentioned above, consideration of the characteristic altitude and relief, mainly using the hydrographic map (DNPM, 1984; IBGE, 2007), which permitted the fine-tuning the zonal boundaries, accounting for the climatic conditions that were considered to produce extreme rainfall events and the greatest hazards and disasters for each zone and the selection of typical examples of hazards and disasters associated with the economic, social, human and environmental losses.

x Considering the hazard and disaster zoning, population density and infrastructure, we developed an assessment of the degree of vulnerability for each of the more affected zones. The assessment considered 3 levels (low, moderate and high degree of vulnerability) based on the following 2 aspects: first, the hazard types and their intensity/magnitude and frequency (Low degree - hazards with low frequency and intensity/magnitude; Moderate degree - hazards with moderate frequency and intensity/magnitude; High degree - hazards with high frequency and intensity/magnitude) and second, the population density, affected environmental elements and urban and/or regional infrastructure (Low degree - low population density, small affected areas (less than 5 ha) and low density of infrastructure; Moderate degree - medium population density, medium-sized affected areas (6 to 50 ha) and low density of infrastructure but of great social and economic importance; High degree - high population density, large affected areas (> 50 ha) and medium to high density of infrastructure).

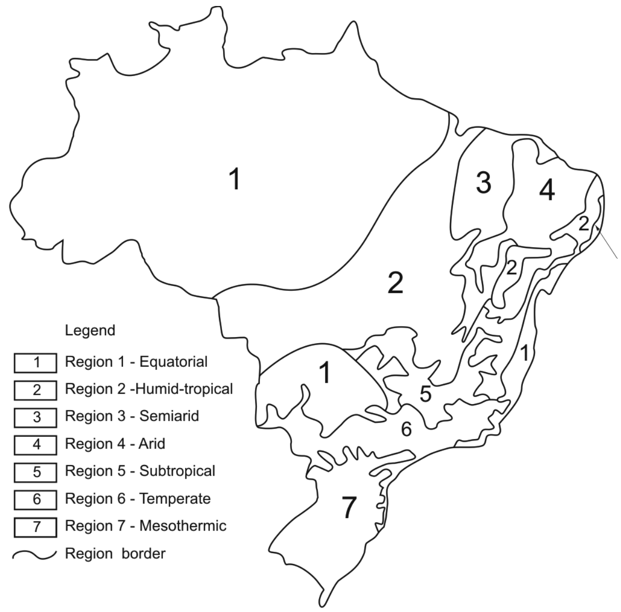

Figure 2 - The main climatic regions of Brazil.

4. The General Environmental Characteristics of Brazil

Brazil is located between the latitudes of 34º South and 5º North and is approximately 4,300 km in the longest north-south direction and 4,150 km in the longest east-west direction, covering 8.5 million km^2 in the Northern and Southern Hemispheres. Climatically, the country includes seven major zones (Fig. 2), varying from wet tropical to sub-humid mesothermic; the main characteristics of the regions are listed in Table 1.

The relief of Brazil includes altitudes varying from 0 to 3,000 m. Approximately 99% of the country is from 0 to 1,200 m (0 to 200 m - 41%; 200 to 500 m - 37%; 500 to 800 m - 15%; 800 to 1,200 m - 6%); 0.5% from 1,200 to 1,800 m; and 0.5% higher than 1,800 m. The population density (Fig. 3) is divided into three categories: less than 10 inhabitants per km^2 (predominantly the northern and western portions), between 10 and 50 inhabitants per km^2 and greater than 50 inhabitants per km^2 (mainly in the south-eastern and southern regions). The population data were obtained from IBGE (2010).

5. Hazard Sources on Brazil

Generally, a hazard is characterized as an event that has a probability of occurrence associated with a specific area and whose intensity is greater than a predetermined limit (a safety threshold) that makes it different from a common event. However, when an event exceeds the safety threshold, it is classified as a hazard with different probabilities and intensities. Some of these hazards result in disasters, producing heavy economic, social and environmental losses or even killing hundreds of people.

The main observed natural and anthropogenic hazard sources that occur in Brazil are generally of a climatologi-

Table 1 - The basic characteristics of the main climatic regions of Brazil.

Main climatic region	Wetness	Average Temperature (°C)	Dry season (months)	Variation of rainfall (mm)
1	Humid	Tropical - > 18	< 3	1, 750 to 3,300
2	Humid	Tropical - > 18	4 to 5	1,000 to 2,250
3	Semiarid	Tropical - > 18	6	750 to 1,500
4	Arid	Hot - > 18	7 to 11	300 to 1,000
5	SubHumid	Subtropical - 15 to 18 at least 1 month	4 to 6	700 to 1,750
6	Humid	Temperate - 15 to 18 at least 1 month	< 3	1,200 to 4,500
7	SubHumid	Mesothermic - 10 to 15	< 5	1,250 to 2,300

Figure 3 - The population density in Brazil.

cal or geological-geotechnical nature, including seismic events, wind, tides, dry season, air pollution, salinization/saline soils, flooding, continental and coastal erosion, silting/sedimentation, subsidence (karst and underground excavation), gravitational mass movements, expansive soil and rock, groundwater pollution, compressible and collapsible soils, pipeline and dam ruptures, spontaneous combustion of turf materials, desertification, surface water pollution, soil pollution, dangerous components in the soil and water, frost, soil liquefaction, dune movements, radioactive spills, natural radiation, wastes and earth fill on the slopes, surface water flow and sanitary landfills. The main triggers of the natural and many anthropogenic hazards in Brazil are rainfall (time and intensity greatly impact its effects) and land use, both of which have an adverse effect on other environmental factors. However, the occurrence of geological, geotechnical and some anthropogenic hazards is directly influenced by the intrinsic properties and variability of the geological materials (unconsolidated materials, rock substrate and the depth of the saturated zone) and their spatial distributions.

6. The Distribution of Hazard Sources

The distribution of hazards and disasters in Brazil was determined based on data collected from the different types of records and considering hazards of all magnitudes and intensities.

According to the data, 28 different types of geological, geotechnical, hydrological, climatological and man-made hazard sources were observed. The distribution of the main hazard sources for each state in Brazil is shown in Fig. 4. The economic, environmental, human and social losses in Brazil have increased significantly over the last 50 years due to disasters resulting from such natural and man-made hazards. Even low-magnitude seismic activity has produced economic losses.

In 2010, Brazil had 5,561 municipalities, and approximately 1,200 have been heavily affected by some hazard over the previous 10 years. Because of the lack of adequate engineering geological mapping, hazard maps or risk charts, territorial planning in the country is not adequate. This lack of planning associated with the lack of adequate laws and sub-optimal land use practices, have led to the increased number of disasters that have resulted in economic losses on the order of billions of USD per year.

As of January 2012, more than 500 municipalities have been affected by hazards that caused disasters (drought, landslides, flooding) in Brazil (300 of them are in the most populous regions), with economic losses greater than 7 billion USD, and a total of 5 million people have been seriously affected, distributed in two groups of states: (i) the states of Minas Gerais, Rio de Janeiro and Espirito Santo, where the economic losses were greater than 5 billion USD; and (ii) the states of Rio Grande do Sul, Santa Catarina, Paraná, Bahia and São Paulo, where the economic losses due to drought were greater than 2.5 billion USD.

Table 2 shows the number of municipalities per state and the main large cities, predominantly state capitals (locations shown in Fig. 5), that were affected by natural and man-made hazards and/or disasters, which might result in social, economic and environmental losses. These municipalities and cities require the adoption of structural measures for prevention and control, and they also require the development of new disaster mitigation policies. The level of knowledge of the environmental components of the ground, especially the geological aspects, is below the level necessary for technical analysis. The areas where prevention and control measures have begun represent a very

Figure 4 - The distribution of the recorded geological, geotechnical, hydrological, climatological and some anthropogenic hazard sources and/or disasters in Brazil. Legend: 1-Seismic activity, 2-Wind, 3-High tides, 4-Drought, 5-Air pollution, 6-Saline soils/salinization, 7-Flooding (natural and human-induced), 8-Continental and coastal erosion, 9-River, lake and reservoir sedimentation, 10-Subsidence (karst and underground excavation), 11- Gravitational mass movements, 12-Expansive soils and rocks, 13-Groundwater pollution, 14-Settlement and collapsible soils, 15-Pipeline and dam (tailing and power) ruptures, 16-Spontaneous fire in peat bogs, 17-Desertification, 18-Surface water pollution, 19-Soil pollution, 20-Dangerous components in soil and water, 21-Hoarfrost condition, 22-Soil liquefaction, 23-Dune movements, 24-Radioactive spill, 25-Natural radioactivity, 26-Uncontrolled earth fill and waste disposal on slopes, 27-Concentrated surface water flow, 28-Pollutant sources.

small percentage of the total area of Brazil. These cities urgently need geological and geotechnical studies to produce engineering geological and hazard maps for the development of risk charts.

7. Hazard and Disaster Zoning

After the inventory was developed, it was analysed, and the collected data permitted the delimitation of the

Table 2 - The number of municipalities and major cities affected and registered as hazard and disaster sources in Brazil.

State	Number of municipalities affected	Most populous city affected by the disasters		Hazard sources
			Population (10^6 inhabitants)	
São Paulo	173	Metropolitan Region of São Paulo	20	Flooding, gravitational mass movements, silting, subsidence, erosion, groundwater pollution
Rio de Janeiro	52	Metropolitan Region of Rio de Janeiro	10	Flooding, gravitational mass movements, silting, subsidence, erosion, settlement
Minas Gerais	335	Metropolitan Region of Belo Horizonte	5	Flooding, gravitational mass movements, silting, subsidence, erosion
Rio Grande do Sul	320	Metropolitan Region of Porto Alegre	5	Flooding, gravitational mass movements, silting, subsidence, erosion
Paraná	180	Curitiba	4	Flooding, gravitational mass movements, silting, subsidence, erosion, expansive materials
Pernambuco	38	Recife	3	Flooding, gravitational mass movements, silting, subsidence, erosion, groundwater pollution
Bahia	48	Salvador	4	Flooding, gravitational mass movements, expansive materials
Ceara	31	Fortaleza	3	Flooding, gravitational mass movements, silting, subsidence, erosion, groundwater pollution, dune movements
DF		Brasília	3	Erosion, collapsible soils
Amazonas	15	Manaus	1	Flooding, erosion, gravitational mass movements
Mato Grosso	51	Cuiabá	1.5	Flooding, erosion, silting
Rio Grande do Norte	23	Natal	1	Dune movements, coastal erosion
Santa Catarina	293	Florianópolis	0.5	Flooding, gravitational mass movements, streambank erosion, erosion
Mato Grosso do Sul	78	Campo Grande	1	Erosion, collapsible soils
Para	35	Belém	1	Flooding ,coastal erosion
Espírito Santo	26	Vitória	1	Flooding ,gravitational mass movements
Goiás	50	Goiânia	2	Erosion
Rondônia	7	Porto Velho	0.5	Flooding, streambank erosion
Alagoas	15	Maceió	0.5	Flooding, landslides, erosion
Acre	10	Rio Branco	0.3	Flooding, erosion, collapsible soil
Tocantins	16	Palmas	0.2	Flooding, gravitational mass movements
Sergipe	8	Aracaju	0.6	Flooding, gravitational mass movements
Amapá	3	Macapá	0.4	Flooding, streambank erosion
Roraima	3	Boa Vista	0.45	Flooding, erosion, wet areas
Paraíba	10	João Pessoa	0.7	Flooding, erosion
Piauí	20	Teresina	0.8	Flooding, erosion, silting
Maranhão	15	São Luis	1	Flooding, erosion

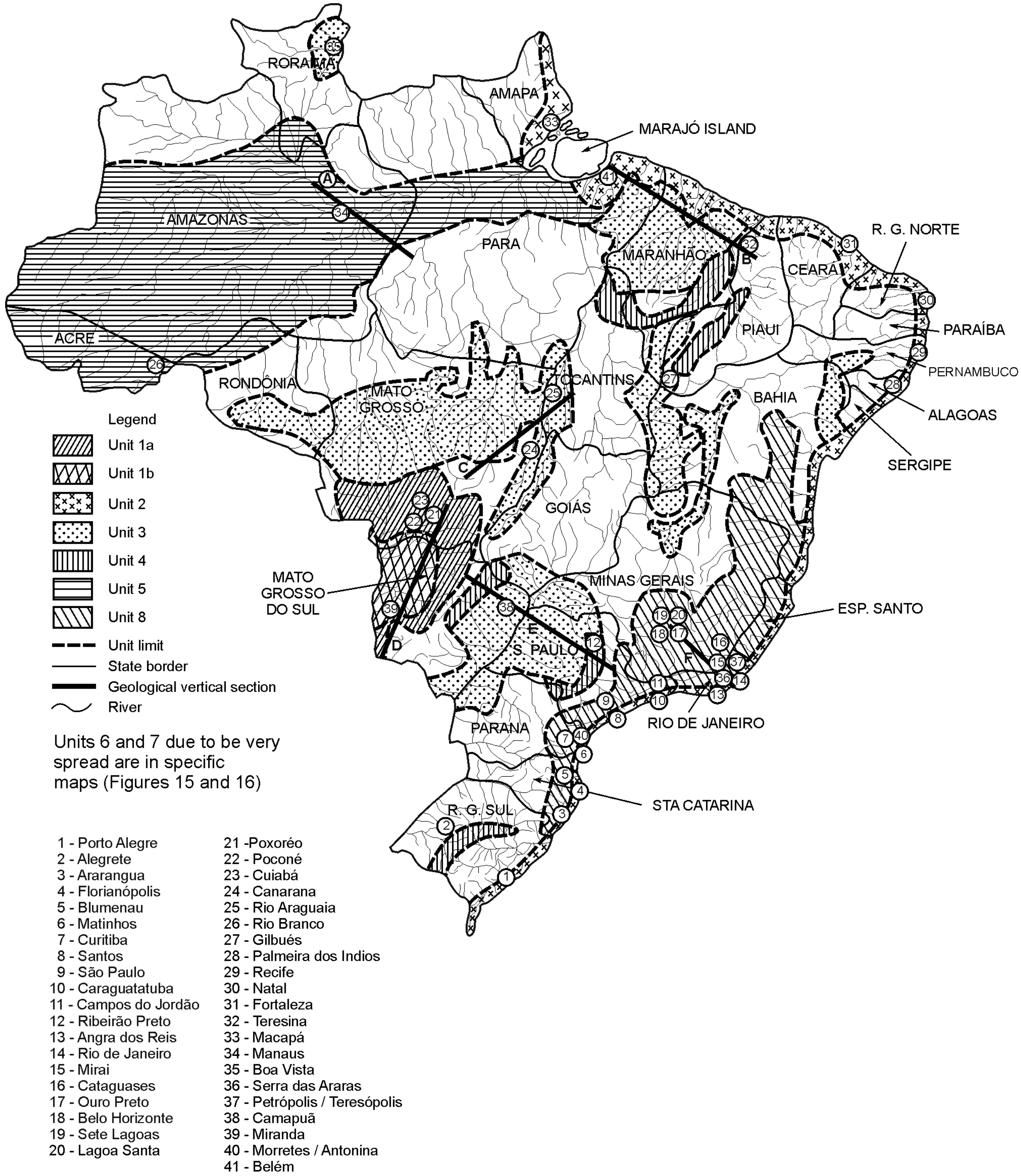

Figure 5 - The distribution of the terrain zones most affected by hazards and/or disasters in Brazil.

eight most affected zones considering the types and intensities of natural and man-made hazards and disasters. For different zones, selected examples that are representative of the hazards and disasters common in the zone are presented. These examples were selected to show the primary mechanisms, magnitudes, affected areas and intensities. Specific locations of all of the cities, sites and examples considered in each zone are shown in the maps. The geological vertical sections were based on geological maps from CPRM (1971), DNPM (1984), CPRM (1983), DAEE/UNESP (1984), MINEROPAR (2005), UNB (2008), CPRM (2007) and IBGE (2007). Figure 5 shows six zones: Zone 1 - Pantanal Basin (flooding, silting and erosion hazards), Zone 2 - Coastal zone and continental strip, Zone 3 - Composed of sandstones and sandy unconsolidated materials, Zone 4 - Aeolian sandstones, Zone 5 - The Amazon region and Zone 8 - Areas affected by natural disasters. The others two zones (Zone 6 - Areas affected by seismic activity and Zone 7 - Areas composed of carbonate rocks) are represented in specific maps.

7.1. Zone 1 - Pantanal Basin (flooding, silting and erosion hazards)

With regard to altitude and geological material, the basin can be divided into two parts (Fig. 6). Zone 1.a is a marshland of Tertiary and Quaternary sediments with an average altitude of approximately 100 m (flooded portion). This zone is composed of an extremely vulnerable and unique landscape (Ab'Sáber, 1988). During the rainy season, this area receives water from the higher portions of the basin (Zone 1.b) via several large rivers that drain large areas. The waters transport a major sediment load derived from the erosion of sandy geological materials (rock and unconsolidated materials). This scenario causes intense silting, the creation of sand bars and marginal erosion. The southern portion of Zone 1.a, near the cities of Miranda and Aquidauana (Mato Grosso do Sul State) (site 39 - Fig. 5), suffered intense flooding in March of 2011, and the water reached 15 m above the normal level of the rivers (see the great extent of the affected areas in Fig. 5) and covered more than 10,000 km^2. The second portion (Zone 1.b) ranges in altitude from 100 to 900 m and is used extensively for agriculture and as a pasture. In this area, diffuse, gully and marginal erosional processes are intense. This area is also characterized by the silting of rivers and dam reservoirs as a result of erosion and collapsing soils. Sandy geological materials and intense rains are responsible for the intense erosive processes and the dangers associated with collapsible soils. The city of Cuiabá in Mato Grosso (Site 23 - Fig. 5) is frequently affected by intense flooding. The largest recorded flood occurred in 1974, when the water reached 11 m above the normal level. This flood affected thousands of people and resulted in losses of 1 billion USD.

In this region, there are intense erosional processes (thousands of erosion features) and earth flows, which generate a large amount of sediments. Consequently, the sediment load transported to Zone 1.a has increased significantly, resulting in the silting of the rivers and lakes (Fig. 7).

7.2. Zone 2 - Coastal zone and continental strip

This zone can presents as wide as 100 km (*e.g.*, in the states of Maranhão, Pará and Piauí), encompassing portions of 18 states (Fig. 5). The width depends on the changes in the landscape from the wave break line. Two large areas can be distinguished within Zone 2. The first area is composed of a range of Quaternary and Tertiary sediments. This area is heavily affected by flooding, intense coastal erosion, dune movement, settlement, high tides, expansive materials and man-made hazards. A number of areas within the zone are prone to silting. The second part is made up of igneous and metamorphic rocks overlain by

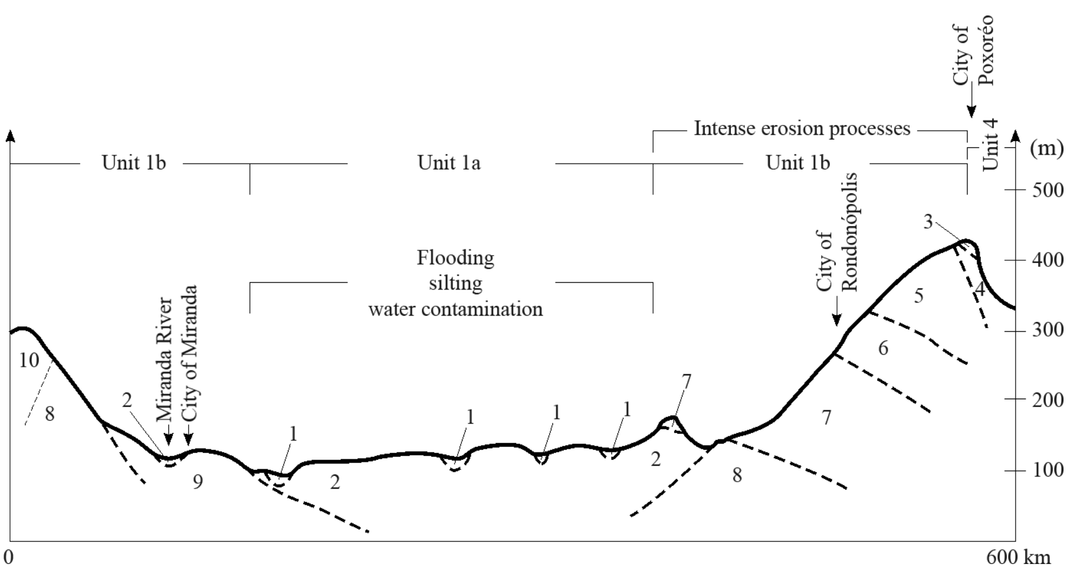

Figure 6 - A schematic geological vertical section of Zone 1 (section D - Fig. 5). Legend: 1 - Alluvial sediments (Quaternary); 2 - Alluvial sediments with gravel layers (Quaternary); 3 - Sandstones, minor siltstones, claystones and conglomerates (Cretaceous); 4 - Aeolian sandstones (Cretaceous); 5 - Sandstones, siltstones, arkoses, shales, rhythmites and diamictites (Carbo-Permian); 6 - Siltstones, shales and sandstones (Devonian); 7 - Sandstones, conglomerates and siltstones (Silurian-Devonian); 8 - Limestones, marls, dolomites, and shales (late Proterozoic); 9 - Phyllites, graphites and hematite phyllites, meta-arkoses, meta-sedimentary rocks and meta-volcanics (middle Proterozoic); and 10 - Schists, quartzites, migmatites and gneisses (undifferentiated Precambrian).

transported and residual unconsolidated materials with different thicknesses, significant relief amplitudes and slopes ranging from moderate to steep. Erosion and gravitational mass movements occur predominantly in this part. Among the cities cited in Table 2, fifteen are located in this zone; all have been heavily affected by disasters with significant economic losses during the last 30 years. In this zone, rainfall can reach as much as 500 mm per month; however, the most frequent monthly high is approximately 300 mm. There is intense coastal erosion in portions of the states of Rio Grande do Sul, Santa Catarina, Paraná (Matinhos region), Rio de Janeiro, São Paulo, Bahia, Pernambuco (Porto de Galinhas region), Rio Grande do Norte and Ceará (city of Fortaleza). Figure 8 shows sites in the cities of Fortaleza and Matinhos that are heavily affected by coastal erosion. More than 100 locations have been affected along the Brazilian coast, resulting in high economic losses due to the disruption of and damage to facilities. Dune movements have been promoted the silting of rivers and affect homes in the urban part of the city of Natal (in the state of Rio Grande do Norte). Major disasters occurred in the city of Salvador (Site 27 - Fig. 5) in 1989 and 1995 due to landslides, where more than 150 people were killed, and dozens of houses and buildings were damaged. The city of Recife (Site 24 - Fig. 5) suffered landslides in 1996, when more than 50 peo-

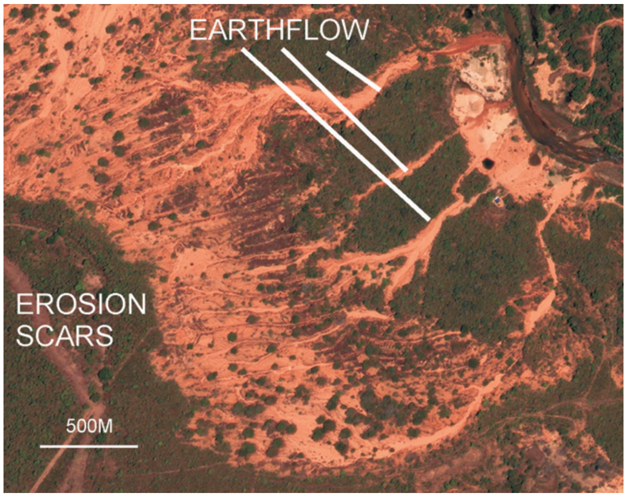

Figure 7 - A general view of an area showing the erosion features associated with earth flows (Site 21 - Fig. 5) in the northern portion of the Pantanal Basin (Poxoréo region - Mato Grosso State).

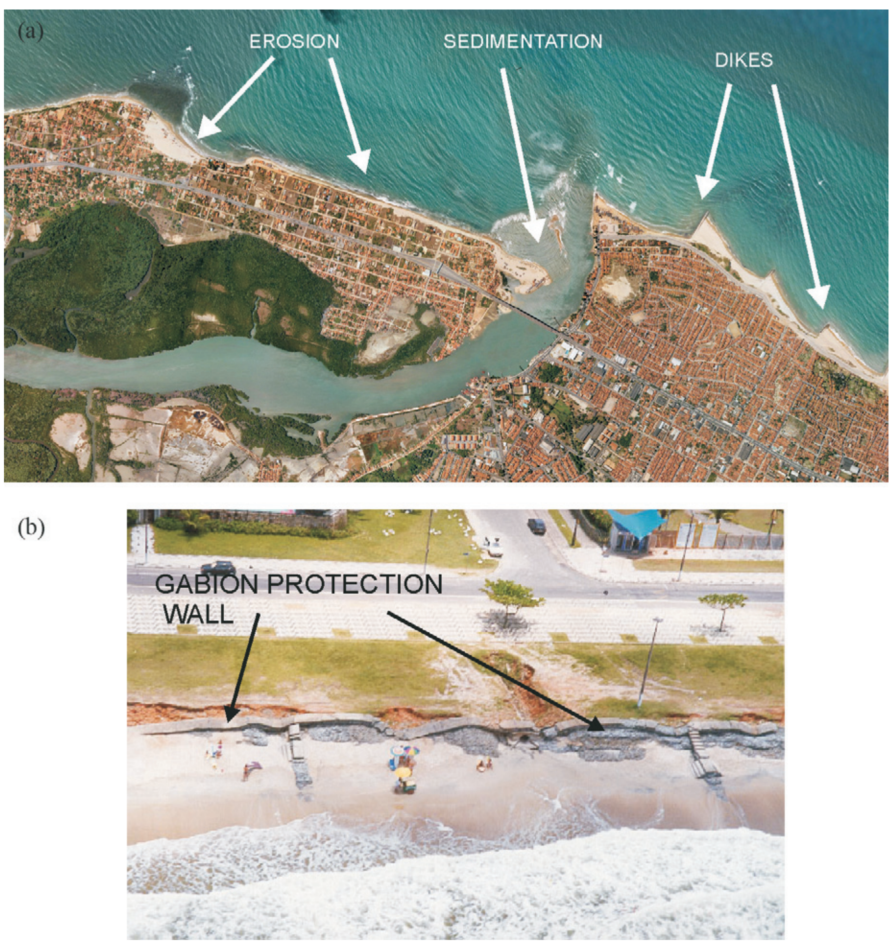

Figure 8 - Examples of sites affected by coastal erosion: a - the city of Fortaleza (Ceará State) with erosion and some dikes to control the sediment flow (Site 31 - Fig. 5); and b - the city of Matinhos (Paraná State) with facilities destroyed (Site 6 - Fig. 5).

ple were killed and hundreds of buildings were damaged. In June 2010, approximately 500 mm of rain fell in the states of Alagoas and Pernambuco, and approximately 40 cities were affected by flooding, erosion and other types of hazards; some cities were more than 80% destroyed. These cities are located in the coastal zone and in areas at higher altitudes. The economic and social damage caused by these disasters required more than $1.5 billion USD to cover direct damage and reconstruction.

7.3. Zone 3 - Composed of sandstones and sandy unconsolidated materials

This zone is composed of areas with sandy sediment, sandstones with different degrees of cementing and sandy transported and residual unconsolidated materials (Fig. 5). The rocky materials are normally covered by up to 100 m of sandy, unconsolidated materials with high porosity, low mechanical resistance, high erodibility index values and a high rate of potential infiltration. Erosive processes; soil collapse; and the desertification and silting of rivers, dams and lakes predominantly occur in these areas. Zone 3 is distributed across different parts of Brazil (Fig. 5), and, as examples, we present two geological vertical sections representative of areas in Figs. 9 and 10 (for one region in the northern part and another in the western part). Intense erosion and silting problems are very common in these areas. In all regions classified as Zone 3, there was estimated to be more than 100,000 erosion features classified as gullies. These intense erosional processes result from intense uses for agriculture and pasture in combination with sandy geological materials and high rainfall intensities and durations. Fig. 11 shows sand deposition (sand bars) in the Parnaíba River (Site 32 - Fig. 5, Piauí State) and erosion features in the Camapuã region (Site 38 - Fig. 5, northeastern part of Mato Grosso do Sul State).

7.4. Zone 4 - Aeolian sandstones

This zone includes areas made up of Triassic sandstones with different degrees of cementing. These sandstones are spread over more than 1 million km^2, but much of that area is covered by other geological materials, as can be seen in the vertical geological section shown in Fig. 12. These geological materials are the most important aquifer in Brazil. Environmental problems, such as sub-superficial water pollution, erosion, silting, desertification and collapsible soils, exist in this area. These sandstones are generally considered to contain good groundwater reservoirs, but the recharge of these reservoirs is directly affected by the use and management of the soil. Another problem is the intense erosive processes associated with the sandy residual unconsolidated material from the sandstones of the lower layers. The southwestern portion of the state of Rio Grande do Sul has been suffering greatly (during the period from November 2011 to March 2012) from intense drought. The economic losses caused by this phenomenon and its associated agricultural damage are on the order of 3 billion USD.

7.5. Zone 5 - The Amazon region

This zone is composed mainly of unconsolidated materials (sediments of Quaternary and Tertiary ages) and weakly cemented sedimentary rocks (Fig. 13). The natural process most common in this region is flooding, but it does not heavily affect the population in small cities because the population density is generally small near the rivers, with the exception of some large cities such as Manaus, Belém, Santarém and Parintins. There are fewer than 10 large cities in the region. Small urban areas near the rivers are prepared

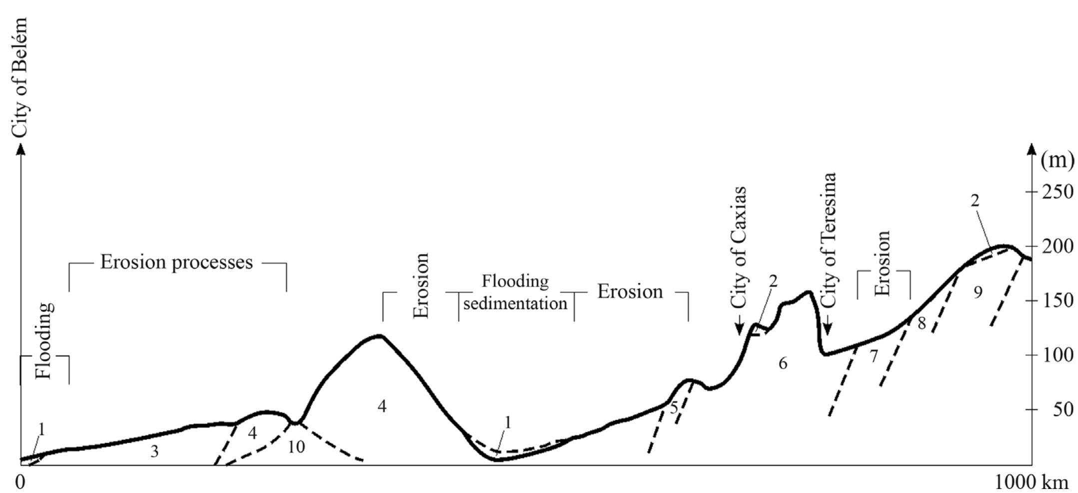

Figure 9 - A schematic vertical geological section of Zone 3 - northern portions (section B - Fig. 5). Legend: 1 - Alluvial sediments (Quaternary); 2 - Clastic sediments and laterites (Tertiary); 3 - Sandstones, siltstones and conglomerates (Tertiary); 4 - Sandstones, limestones, marls and shales (Cretaceous); 5 - Sandstones, shales and limestones (Cretaceous); 6 - Sandstones, siltstones, shales and limestones (Permian); 7 - Sandstones (Carbo-Permian); 8 - Sandstones, siltstones, shales and coal layers (Carbo-Permian); 9 - Sandstones, siltstones and shales (Devonian); and 10 - Phyllites, quartzites and metasedimentary rocks (late Proterozoic).

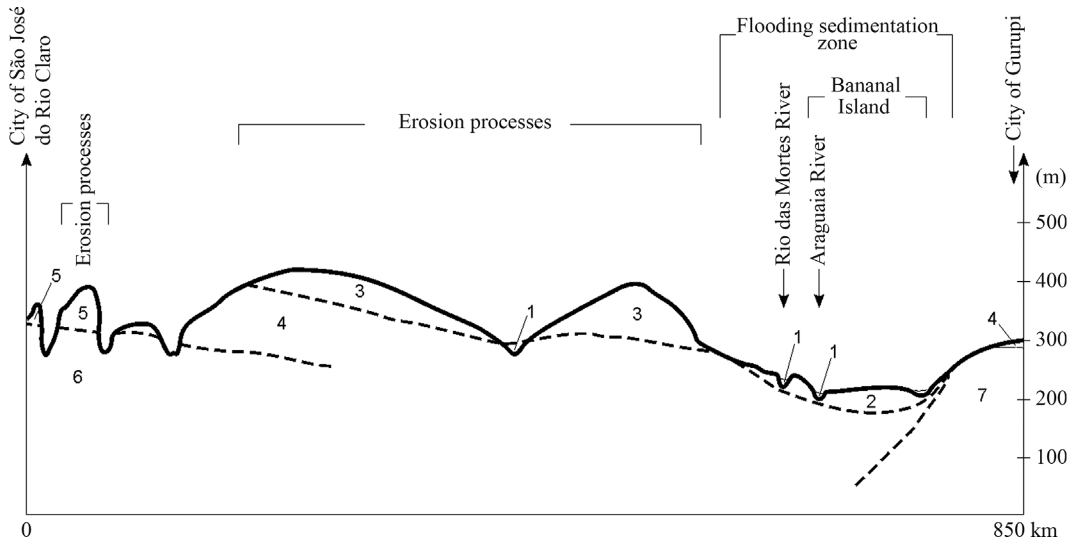

Figure 10 - A schematic vertical geological section of Zone 3 - western portion (section C - Fig. 5). Legend: 1 - Alluvial sediments (Quaternary); 2 - Sandy sediments with gravel layers (Quaternary); 3 - Sandy-silty sediments and laterites (Tertiary-Quaternary); 4 - Clastic sediments and laterites (Tertiary); 5 - Sandstones (Cretaceous); 6 - Sandstones, conglomerates, siltstones and claystones (Palaeozoic-Mesozoic); and 7 - Quartzites, schists, marbles and other metamorphic rocks (middle Proterozoic).

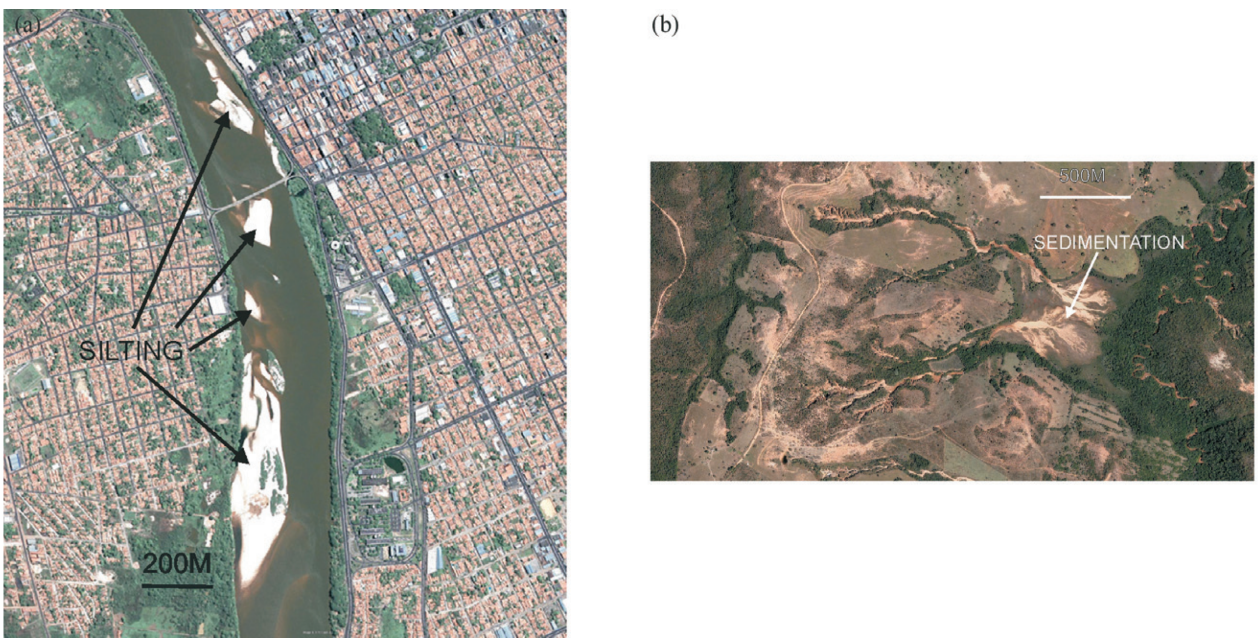

Figure 11 - Areas strongly affected by erosional processes and silting: a) sediment deposits (Site 32 - Fig. 5) in the Parnaiba River (city of Teresina - Piauí State) and b) gullies in the Camapuã region (northeast portion of Mato Grosso do Sul State, Site 38 - Fig. 5).

for and accustomed to this natural process. The floods are intense because the rivers drain very large areas, and the rainfall is controlled by the climatological conditions of the Northern and Southern Hemispheres. However, this region suffers heavily from dry periods when the river water levels decrease so that it is impossible to navigate small boats, which are the main form of transportation and are also used for tourism and fishing, which are very important economic activities.

Urbanisation has affected the equilibrium of the geological materials, generating gravitational mass movements, erosion and other natural processes in the main urban areas such as Manaus, Belem and Macapá (Fig. 14). The metropolitan regions of Belém, Para State, (Site 41 - Fig. 5), and Manaus, Amazonas State, (Site 34 - Fig. 5) have been affected by flooding of up to 15 m (in April 2012). Due to the very flat topography (with an average relief amplitude of less than 5 m) the flooding covers large ar-

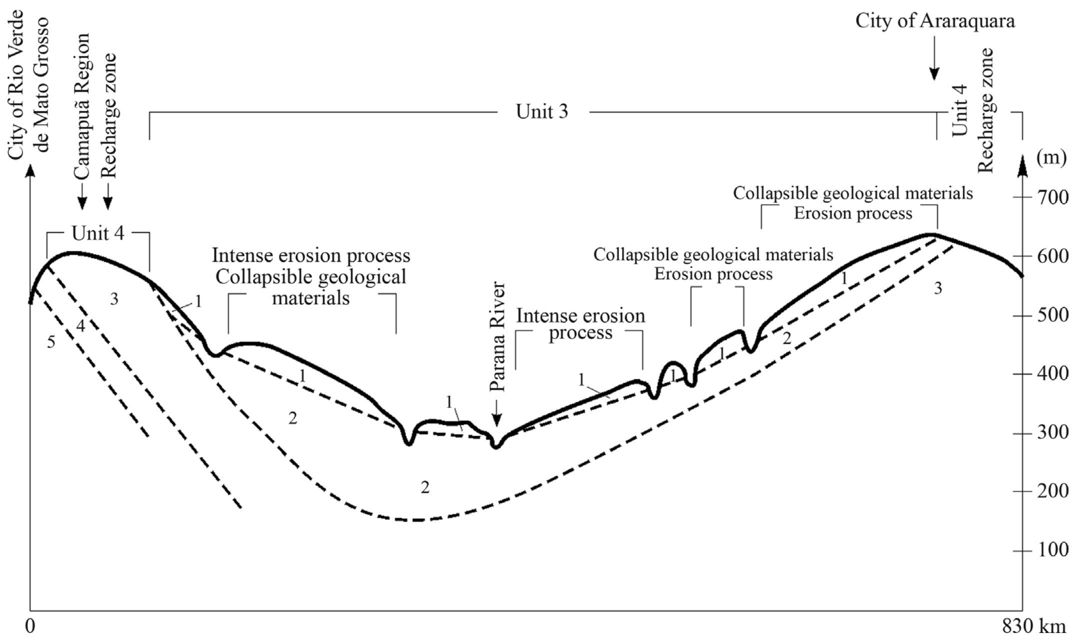

Figure 12 - A schematic vertical geological section of Zones 3 and 4 (section E - Fig. 5). Legend: 1 - Sandstones, siltstones and minor claystones (Cretaceous); 2 - Basalts (Juro-Cretaceous); 3 - Aeolian sandstones (Jurassic); 4 - Sandstones and siltstones (Carboniferous-Permian); and 5 - Siltstones and shales (Devonian).

eas. The Acre and Roraima states were affected by flooding in the January, February and March of 2013.

7.6. Zone 6 - Areas affected by seismic activity

This zone includes areas where the frequency of seismic activity is higher than average for Brazil (Fig. 15). These areas are associated with specific geographic positions that are associated with geological structures. Some of these areas have not suffered economic losses because they have not been affected by high-magnitude seismic activity. However, this area is experiencing increased development, and the seismic aspects have been considered as dynamic parameters in these projects. The majority of earthquakes recorded in Brazil since the 1800s have had Modified Mercalli Intensity lower than 4, with a small percentage (5%) ranging from 6 to 7. The highest recorded intensity according to the Modified Mercalli Intensity scale is 6. Approximately 80% of earthquakes recorded in Brazil between 1800 and the present occurred in the areas noted in Fig. 15.

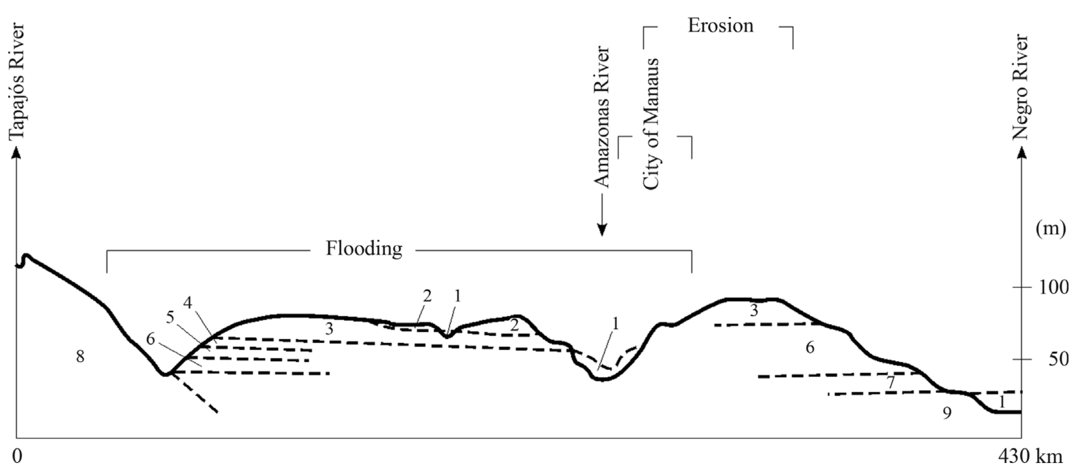

Figure 13 - A schematic vertical geological section of Zone 5 (section A - Fig. 5). Legend: 1 - Alluvial sediments (Quaternary, Tertiary); 2 - Weakly cemented sandstones (Quaternary, Tertiary); 3 - Sandstones, siltstones and shales (Cretaceous); 4 - Sandstones, siltstones, shales and limestones (Carbo-Permian); 5 - Sandstones, siltstones and shales (Devonian); 6 - Sandstones, siltstones and shales (Ordo-Silurian); 7 - Arkoses, conglomerates and sandstones late Proterozoic); 8 - Acid and intermediate volcanics (middle Proterozoic); 9 - Hornblende-gneisses, schists, amphibolites and diorite (Archean).

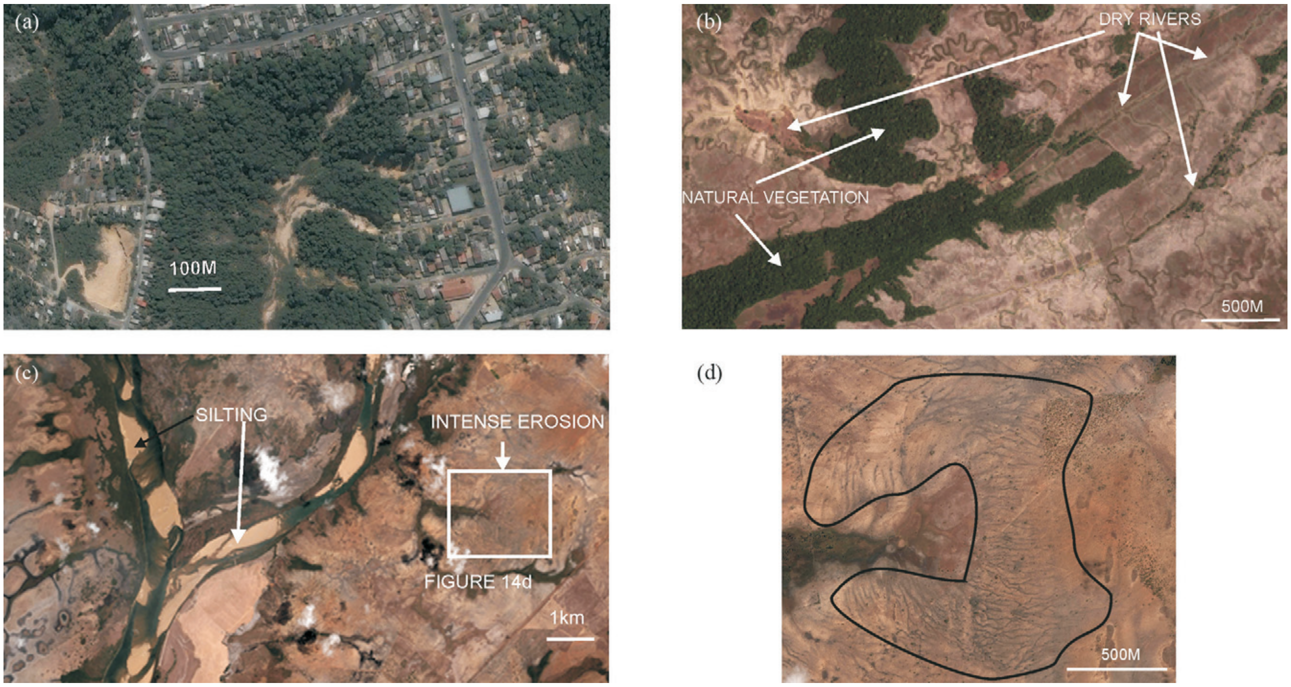

Figure 14 - Degraded areas due to deforestation, overcultivation and overgrazing: (a) Erosion and gravitational mass movement in the city of Manaus, Amazonas State (Site 34 - Fig. 5); (b) Degraded land in the Macapá region, Amapá State (Site 33 - Fig. 5); (c) A river highly affected by silting due to erosional processes in the Boa Vista region, Roraima State; and (d) Detail of intense erosional processes

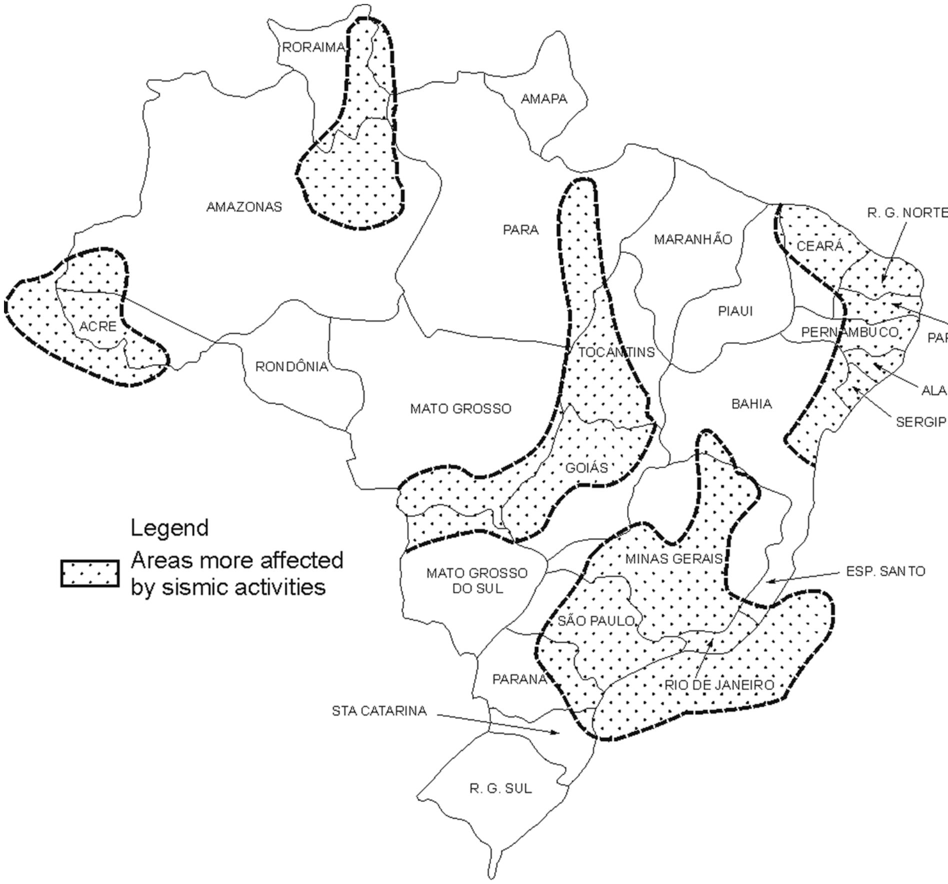

Figure 15 - The regions most affected by earthquakes in Brazil. Modified from (Mioto, 1993), OBSIS (2010) and IAG/USP (2010).

7.7. Zone 7 - Areas composed of carbonate rocks

These regions are composed of calcitic and dolomitic limestones, marbles, and calcareous rocks in different proportions associated with other sedimentary and metamorphic rocks (Fig. 16); carbonate rocks crop out in approximately 10% of Brazil. Depressions, sinkholes and caverns of various sizes occur. In urban areas, this generates problems for construction and the environment. Cities ranging in size from 10 thousand to 2 million inhabitants are affected. Subsidence in rural areas generates problems, such as water accumulation, and prevents the use of heavy machinery in the plantations and even prevents the area from being used as a pasture. There are multiple examples of urban areas (see locations in Fig. 16) affected by subsidence: 1 - The metropolitan region of Curitiba (Paraná State); 2 - Lagoa Santa (Minas Gerais State); 3 - Sete Lagoas (Minas Gerais State), 4 - Laussance (Minas Gerais State); 5 - Vazantes, related to mining (Minas Gerais State); 6 - Cajamar (São Paulo State); 7 - Nobres (Mato Grosso State); 8 - Teresina (Piauí State); 9 - Matozinhos (Minas Gerais State); 10 - Morro do Chapéu (Bahia State); and 11 - Mossoró (Rio Grande do Norte State). In these regions, hundreds of sinkholes have been recorded in the last 20 years, mostly induced by groundwater exploitation. The metropolitan area of Curitiba is the largest of the 11 cited and, consequently, presents the greatest economic losses, mainly in the form of building damage and groundwater exploitation.

7.8. Zone 8 - Areas affected by natural disasters

This zone is the region most affected by natural hazards and disasters, including the 10 largest disasters in Brazil. It includes areas with very steep slopes (greater than 65°) and composed of igneous and metamorphic rocks, mainly granites, migmatites, gneisses, schists, phyllites and limestones (Fig. 17). The altitude is predominantly below 2,000 m, and rainfall can reach 4,500 mm, with daily values of 550 mm. However, the average maximum daily value is approximately 250 mm. These lithologies are associated with weathering profiles with a range of thicknesses and degrees of heterogeneity as well as slopes with different inclinations, from gentle to steep. The variability in the geological materials is very high, which increases the likelihood of diverse natural hazards. In these areas, almost all types of gravitational mass movements and linear erosion occur. These processes are caused by the geological-geotechnical characteristics of the weathering profiles or the unconsolidated materials that are associated with the specific conditions of infiltration, slopes of greater than 65 degrees, discontinuities from different sources parallel to the land surface, artificial embankments with inclinations above the geotechnical limits and earth fills with different degrees of compaction along their slopes. In the last five years, more than 15,000 gravitational mass movements and erosion events have occurred in this area. Among these events, more than 1,000 were classified as hazards, and some became disasters, with a predominance of gravitational mass movements, erosion, sinkholes, peat fires and anthropogenic disasters, such as the leakage of chemicals. Since 1990, large natural hazards have occurred in this

Figure 16 - The distribution of carbonate rocks and the main affected urban areas in Brazil.

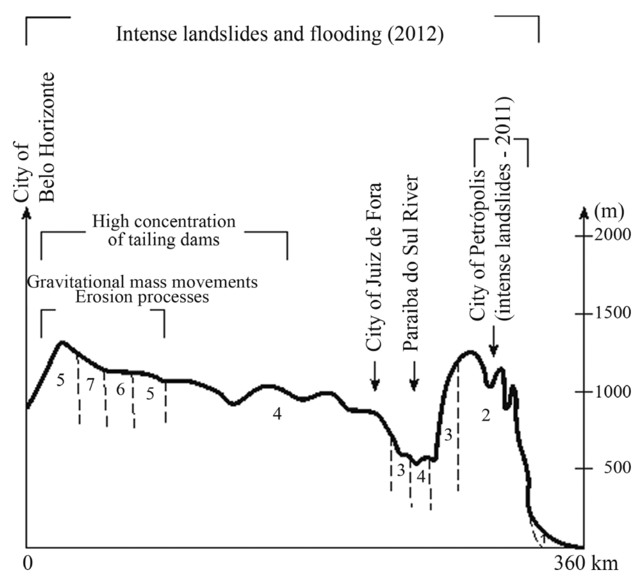

Figure 17 - A schematic vertical geological section of Zone 8 (section F - Fig. 5). Legend: 1 - Alluvial and colluvial sediments (Quaternary, Tertiary); 2 - Granites (late Proterozoic); 3 - Gneisses, migmatites, schists, amphibolites and quartzites (late Proterozoic); 4 - Granulitic gneisses, migmatites, granitoids, gabbros and schists (Archean); 5 - Volcano-sedimentary sequence, quartzites, schists, phyllites and iron formations (Archean); 6 - Quartzites, phyllites, itabirites and schists (early Proterozoic); and 7 - Migmatites, gneisses and granitoids (Archean).

zone, with significant economic losses, and have resulted in the deaths of thousands of people. In December 2010 and January 2011, approximately 400 cities were affected by flooding and landslides of different intensities and magnitudes, including the metropolitan regions of São Paulo, Curitiba and Belo Horizonte. The metropolitan region of São Paulo, the biggest and most economically important urban area in Brazil, is located in this region and is affected annually by intense floods and moderate gravitational mass movements, mostly induced by human interference with the valleys and slopes, which has changed the morphometry and the water dynamics. The annual economic losses can reach 1 billion USD per year, considering that the total extent of the metropolitan region of São Paulo covers 2,500 km^2 and has approximately 20 million inhabitants.

Of the 100 largest disasters in Brazil, many occurred in this zone. Table 3 shows the disasters and the deaths and the economic, social and environmental losses associated with each disaster (the locations are shown in Fig. 5). Table 3 shows that this zone has had, on average, one large disaster every 5 years. The number of hazardous events per year in this zone is very high, but only a small number of these events qualified as disasters, even in urban areas. Landslides normally occur due to changes in the mechanical strength of the geological materials, the inclination of the slope and favourable discontinuities, but landslides normally qualify as disasters if they develop into earth flows due to surface water accumulation and the number of rock blocks transported with the unconsolidated materials. In 2011, there were the same types of rain (intensity and duration) as in 2008 in the state of Santa Catarina; the rain resulted in flooding but not gravitational mass movement. Similar conditions were present in 1967, when major disasters occurred in the Serra das Araras region (city of Piraí) and the city of Caraguatatuba but not at other sites with the same geological characteristics (even though those sites experienced more rain). The fundamental factor for triggering gravitational mass movement in this zone is the rain distribution during the months before the occurrence of the hazardous events rather than high rain intensity over a short du-

Table 3 - The largest disasters occurring in Zone 8.

Year	Site	Type of hazard	Economic, social and environmental losses	Number of casualties
1800 to the present	São Paulo, São Paulo State	Flooding (average frequency less than 5 years)	Disruption of services until high economic losses occurred, with the destruction of buildings, roads and bridges	
1811, 1906, 1924	Rio de Janeiro, Rio de Janeiro State	Flooding	Disruption of services until high economic losses occurred, with the destruction of buildings, roads and bridges	100?
1911	Blumenau, Santa Catarina State	Flooding	People and infrastructure services were severely affected	
1928	Santos, São Paulo State	Landslides	Partial destruction of a hospital	60
1929	São Paulo, São Paulo State	Flooding	People were injured, and services were severely damaged	
1944	Caraguatatuba, São Paulo State	Landslides, flooding		
1948	Rio Paraiba do Sul Valley	Group of landslides	Hundreds of buildings	250
1956	Santos, São Paulo State	Landslides	Destruction of 100 houses	70
1966	Rio de Janeiro, Rio de Janeiro State	Landslides	Destruction of buildings and houses	200
1967	Serra das Araras - city of Piraí (Rio de Janeiro State)	Landslides	Roads, hydroelectric power and dozens of buildings	1,800
1967	Caraguatatuba, São Paulo State	Landslides	Destruction of 500 buildings and roads	150
1972	Campos do Jordão, São Paulo State	Landslides	Destruction of 80 buildings	20
1983	Blumenau, Santa Catarina State	Flooding	200,000 people were affected	50
1986	Lavrinhas, São Paulo state	Landslides	Destruction of houses, roads and bridges	20
1986	Cajamar, São Paulo State	Subsidence (karst)	Destruction of dozens buildings	

Table 3 (cont.)

Year	Site	Type of hazard	Economic, social and environmental losses	Number of casualties
1987	Rio de Janeiro	Flooding	20,000 people affected	300
1988	Cubatão, São Paulo State	Landslides and earth flow	Destruction of dozens of buildings	15
1988	Petrópolis, Rio de Janeiro State	Landslides	1,500 houses were destroyed ,and more than 5000 people were affected	200
1988	Rio de Janeiro	Landslides	Destruction of dozens of buildings	40
1989	São Paulo	Flooding, landslides	Destruction of dozens of buildings	20
1990	Blumenau, Santa Catarina State	Landslides, flooding	Houses, roads and bridges were destructed	20
1992	Belo Horizonte, Minas Gerais State	Landslides, flooding	Houses and roads were destroyed	20
1992	Contagem, Minas Gerais State	Landslides	Hundreds of buildings were destroyed	40
1995	Araranguá, Santa Catarina State	Landslides, flooding	Houses, roads, and plantations were damaged	40
1997	Ouro Preto, Minas Gerais State	Landslides, flooding	High economic, environmental and artistic losses	15
1999/2000	Campos do Jordão, São Paulo State	Landslides	Houses and roads were damaged	20
2002	Angra dos Reis, Rio de Janeiro State	Landslides, flooding	Railroads, buildings	52
2004	Santa Catarina State	Hurricane (wind speed higher than 155 km/h - category 1 on the Saffir-Simpson scale)	1,500 houses destroyed and 40,000 damaged. Economic losses higher than 500,000 USD	75
2008	Blumenau, Santa Catarina State	Landslides, flooding	More than 2 billion in economic losses. 1.5 million people were affected	300
2010	Angra dos Reis, Rio de Janeiro State	Landslides	300 houses and roads	50
2010	Paraty, Rio de Janeiro State	Landslides, flooding	Roads, houses and others types of buildings were damaged	10
2010	São Luiz da Paraitinga, São Paulo State	Flooding, landslides	Hundreds of buildings were destroyed	50
2010	Niterói, Rio de Janeiro State	Landslides	Destruction of hundreds of houses	180
2010	Rio de Janeiro	Flooding, landslides	Destruction of hundreds of houses	300
2011	Mountain region, Rio de Janeiro State	Landslides, flooding	10 billion USD in damages	1000
2012	Mountain region, Rio de Janeiro State	Landslides	2 billion USD in damage and damage to hundreds of buildings	50
2012	Minas Gerais State (110 cities were affected)	Landslides, flooding	More than 3 million people affected and economical losses higher than 3 billion	30
2012	Rio Grande do Sul State (50 municipalities affected)	Drought	3 billion USD	10
2012	Santa Catarina State	Landslides, flooding	500,000 USD	
2013	Mountain region, Rio de Janeiro State	Landslides, flooding	100 houses destroyed and hundreds damaged. Economic losses higher than 3000,000 USD	20

ration. Hundreds of datasets describing the relationships between rain and gravitational mass movements have been collected by CNR/IRPI (2010), and the results indicate that each region is characterised by specific interactions between geological materials and rain. In Brazil alone, there are dozens of examples of this type of relationship for regions separated by only short distances (Guidicini & Iwasa, 1976; Tatizana, 1987; Elbachá *et al.*, 1992; D'Orsi *et al.*, 1997). These complex relationships reflect the fact that gravitational mass movements depend on the combination of several factors, mainly geological, geotechnical and hydrogeological. Some of the disasters presented in Table 3 were chosen as examples, and a small group of characteristics is presented below to show the general intensities and magnitudes of losses. During the period from January to March of 1967, Serra do Mar Mountain, mainly in the states of São Paulo and Rio de Janeiro, suffered daily from intense rainfall of as much as 450 mm per day, with values reaching 300 mm in 3 hours at some sites. In January, a large group of landslides and earth flows reached the Serra das Araras region (near the city of Piraí, Rio de Janeiro state) over an area of approximately 3,000 km^2 (this is well described by Jones, 1973), and another group of landslides and earth flows occurred in the city of Caraguatatuba (São Paulo State). Both disasters killed more than 2,000 people, destroyed hundreds of buildings, cars, roads, and plantations and seriously affected public health and social public services (Fig. 18). Intense gravitational mass movements occurred in 1995 in the Araranguá region (Santa Catarina State - Fig. 5) at altitudes between 600 and 1,100 m, affecting 11 municipalities. This event was associated with a rain event with an intensity of 550 mm/day and with a duration of 4.5 hours, and more than 40 people were killed and 20,000 people affected. These shallow landslides and earth flows began mostly at the crests of very steep slopes (scarps), and the earth masses displaced flows down to the feet of the scarps and continued in drainage channels, reaching high velocities and covering great distances. Fig. 19 shows examples of disasters that occurred in the Itajaí River Basin (SC) in December 2008, with losses greater than 2 billion USD. The landslides and earth flows of various intensities (dimensions and volumes) reached infrastructure works, including roads, bridges, buildings and plantations, causing major economic and environmental losses. Landslides began in different positions on the slopes. Part of the materials transformed into earth flows,

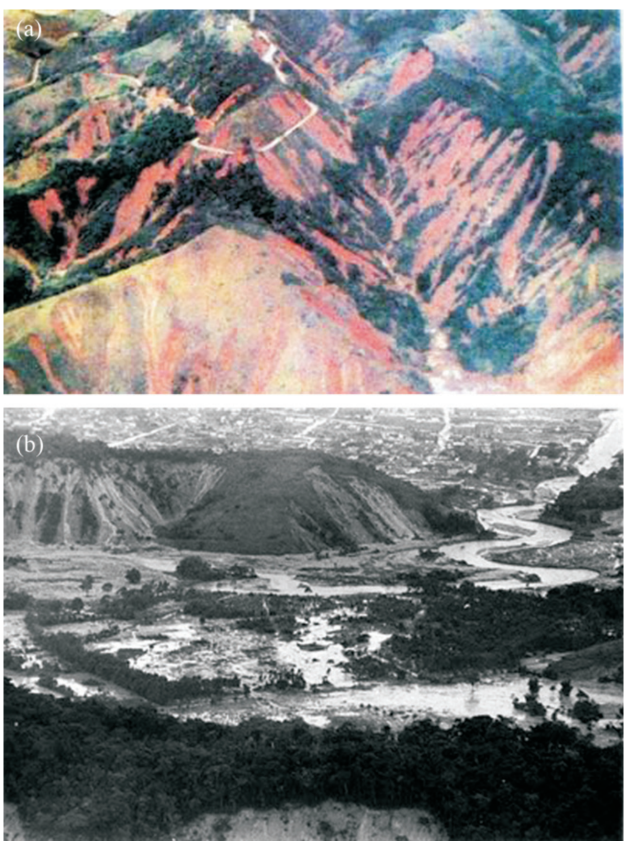

Figure 18 - Landslides in (a) Serra das Araras, Rio de Janeiro State (Site 36 - Fig. 5), and (b) the city of Caraguatatuba, São Paulo State (Site 10 - Fig. 5), in 1967. From Arquivo Base DER.

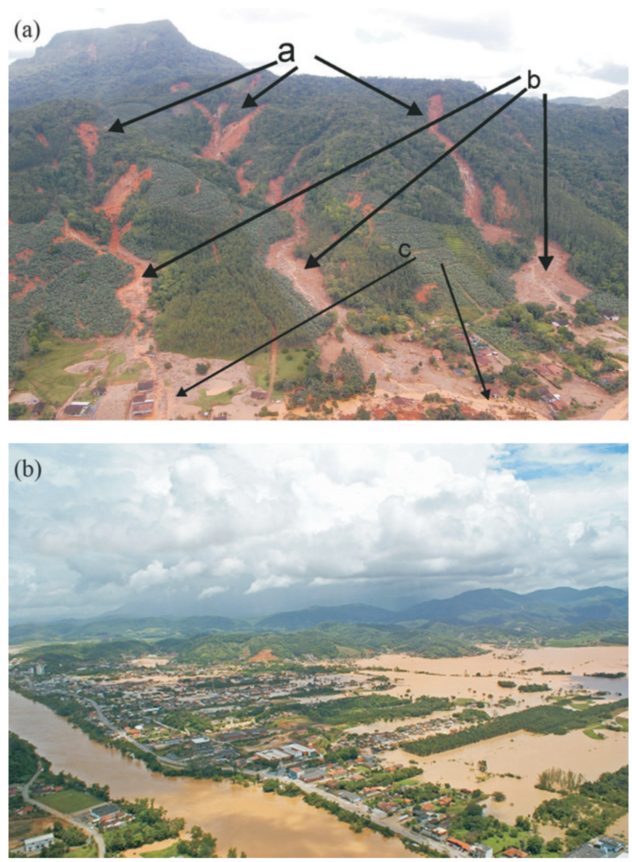

Figure 19 - Examples of natural disasters in the Blumenau region (Itajai Valley, Santa Catarina State; Site 5 - Fig. 5). (a) Gravitational mass movements (a - translational slide, b - earth flow covering buildings, c - valley with geological material transported by several earth flows) and (b) - Intense flooding.

reaching the valleys with accumulated sediments up to 10 m thick. The water level, as a result of flooding, reached 12 m above the normal level of the Itajaí River (although this limit is less than the maximum registered of 17 m) and killed more than 300 people. Flooding presented differently based on the type of valley; narrow valleys frequently suffer more losses than wide valleys. There were also gravitational mass movements in the Angra dos Reis region (Rio de Janeiro State) during the months of March and April 2010. During these events, dozens of people died, and the direct and indirect economic damages surpassed \$500 million USD. During April 2010, the cities of Niteroi and Rio de Janeiro were strongly affected by landslides and earth flows that killed more than 400 people and resulted in more than 3 billion USD in damages. During January 2011, January 2012 and March 2013 the mountain region (Rio de Janeiro State) was strongly affected by rainfall on some days, triggering many large gravitational mass movements (*e.g.*, landslides, earth flows, rock falls) and flooding in the municipalities of Teresópolis, Nova Friburgo, Petrópolis, Areal, Sumidouro, São José do Vale do Rio Preto and Itaipava, affecting more than 100,000 people and killing more than 1,000. The intensities and sizes of the landslides varied significantly depending on the spatial arrangement of geological material layers, slope shape, slope profile and inclination. The economic losses exceeded 5 billion USD. The environmental and social losses are impossible to estimate because the cities, people, plantations and environment were strongly modified by the geological material displacement within the valleys and flood plains. In the first days of March of 2011, the region of Antonina and Morretes, in Paraná State, (Site 40 - Fig. 5) was heavily affected by more than 3,000 gravitational mass movements during the second week of March 2011. The volume of the displaced geological material varied from 10 to 200,000 m^3 (Fig. 20). Geologically, the region is composed of amphibolites and gneisses covered by weathered rock, saprolite and unconsolidated material layers, and talus and colluviums occur on some parts of the slopes. The slope inclinations vary from 10 to 70°. Approximately 20% of the gravitational mass movements occurred at locations with morphometric changes due to human interference, and the rest occurred in natural terrain with dense vegetation. These events injured more 10,000 people (approximately 20% of the total population), resulted in deaths, and generated high economic and social losses as well as significant environmental losses due to very large sediment load transported by earth flow to the ocean with its chemical products, including liquid and solid urban wastes and other types of dangerous chemical products (Fig. 20). From December 2011 to January 2012, the southern and southeastern regions of Brazil were affected by natural disasters, causing the destruction of roads, buildings, bridges and other facilities and killing hundreds people.

Figure 20 - Gravitational mass movements in the Antonina and Morretes region, Paraná State (site 40 - Fig. 5). a) General view, b) Sediment load generated by gravitational mass movements with chemical and organic compounds in the water of Antonina Bay (shown by the different colours of water).

8. Analysis

In Brazil, the perception of the problem varies; a natural or anthropogenic event can be classified as a disaster only if it leads to a casualty, irrespective of the magnitude or intensity. Therefore, even if a major disaster causes large economic losses, such as by damaging large plantations, it might not be classified as such. This perception complicates the study of hazards and disasters. Dozens of major hazardous events (*e.g.*, landslides and flooding) have occurred in areas with small populations and thus did not result in fatalities or large economic or social losses. However, in the last 30 years, hazardous events have occurred in urban areas, causing disasters with billions of dollars of losses and thousands of deaths. Considering both the distribution of the hazard types and the disasters in each state and their characteristics, an assessment was made to classify each hazard/disaster type per state into one of the 6 levels, as described in item 8 in the methods section. The results are presented in Table 4.

Considering the data from Table 4, the states most affected by hazards and disasters are Santa Catarina, São Paulo, Rio de Janeiro, Paraná and Minas Gerais; the most affected cities are the metropolitan regions of São Paulo, Rio de Janeiro, Belo Horizonte, Curitiba, Florianopolis,

Table 4 - Gradation of the levels of hazards and disasters for the states.

States/hazard/disaster sources	AP	RR	PA	AM	MA	PI	CE	RN	PB	PE	AL	SE	BA	MG	ES	RJ	SP	PR	SC	RS	MS	MT	RO	AC	GO	TO
1-Seismic activities			2	2		1	2	3	3	3			2	2		3	3				1	1		3	2	2
2-Wind						2	3	3									1									
3-High tides	1		1		1	1	2	2	1	1	1	1	1		1	1	1	2	2	2						
4-Drought				1	2	4	4	3	3	2	1	1	2	2						3	1					
5-Air pollution														1	3	3	5									
6-Saline soils/Salinization						1	2	2	2	1	1	1	1	1	1	1	1	1	1	2	1	1	1			
7-Flood (natural and in-duced)	1	1	2	4	2	1	2	1	1	2	2	1	2	2	1	5	6	3	4	3	1	2	1	1	1	1
8- Continental and coastal Erosion	2	2	2	1	2	2	3	2		2	1		1	3	1	4	5	4	4	4	4	4	2	1	3	2
9-River, lake and reservoir sedimentation.		2	2	2	1	2	2	1	1	1		1	1	2	1	2	3	2	2	2	3	3	1	1	3	2
10-Subsidences (Karst and underground excavation)				1									1	4		1	2	4	1	1	1	2			1	1
11- Gravitational mass movements				1	1		2	1		2	1		2	4	2	5	6	4	4	3		1				
12-Expansive soils and rocks							2	1		1			1	2		1	2	3	1	1		1		1		
13-Groundwater pollution							2	1		2			2	3		4	5	2	2	2		1	1			
14-Settlement and collaps-ible soils	1		2	2						2			1	2		2	3	3		2	2	1		1	1	1
15- Pipeline and power and tailing dam ruptures														4	1	2	3	2	1			1	1		1	1
16-Spontaneous fire in peat														1		1	2	1	1	1		1				
17-Desertification		2	1		2	3	2	2	1					1			1			2	1	2			1	1
18-Surface water pollution			2	2	1	1	2	1					1	2	1	3	4	2		2		1	1			
19-Soil pollution		1	2	2						1			2	3		2	3	2		2		2	1			
20-Dangerous components in soil and water																1	2	1		1						
21-Hoarfrost condition																		1	1	1						
22-Soil liquefaction																1	1									
23-Dune movements					2		3	4		1																

Table 4 (cont.)

States/hazard/disaster sources	AP	RR	PA	AM	MA	PI	CE	RN	PB	PE	AL	SE	BA	MG	ES	RJ	SP	PR	SC	RS	MS	MT	RO	AC	GO	TO
24-Radioactivity spill														1		2	2									
25-Natural radioactivity													1	1			1									
26-Uncontrolled earthfill and waste disposal on slopes			1		1		2			1			1	3		3	4	2	2	2	1	1			1	1
27-Concentrated surface water flow																	2	1		1		1			1	
28-Pollutant sources							1			1			1	3	1	3	3	2	1	2	2	2				

Legend: AP – Amapá, RR – Roraima, PA – Pará, AM - Amazônia, MA – Maranhão, PI – Piauí, CE – Ceará, RN – Rio Grande do Norte, PB – Paraíba, PE – Pernambuco, AL – Alagoas, SE – Sergipe, BA - Bahia, MG - Minas Gerais, ES - Espírito Santo, RJ - Rio de Janeiro, SP - São Paulo, PR – Paraná, SC - Santa Catarina, RS – Rio Grande do Sul, MS - Mato Grosso do Sul, MT - Mato Grosso, RO – Rondônia, AC – Acre, GO - Goiás, TO – Tocantins.

Salvador and Recife. Half of the Brazilian population lives in these states (Fig. 3).

Zones 3 and 5 are most affected by agriculture; in Zone 5, due to deforestation and changes in the surface layers of the soils, whereas Zone 3 presents problems related to relief and runoff changes, decreases in the water infiltration and other problems. Zone 2 is the one most affected by urbanization because it contains the majority of the large cities. The relief and runoff changes in this zone have been significant, which have resulted in very dangerous flooding.

In Zone 8, man-made hazards are commonly related to several sources, but tailing dams and sanitary landfills are responsible for significant economic and environmental losses. Tailing-dam ruptures have destroyed buildings, bridges and plantations in large areas, contaminated river waters and occasionally even reached the ocean. The sanitary landfills and others types of waste deposits generate environmental problems related to groundwater contamination and sometimes result in economic and environmental losses due to the rupture of waste masses. In this zone, thousands of land areas are degraded around hundreds of sanitary landfills (controlled and uncontrolled).

Continental erosion, silting, salinization, pollutant sources, desertification and water pollution have generated very high environmental losses, mainly in Zone 1, followed in decreasing order of severity by Zones 2, 5 and 3. However, floods and gravitational mass movements are responsible for more than 80% of the fatalities. For example, erosion has deeply affected the facilities in urbanized areas, even in small cities, mainly damaging streets, water pipes, pluvial drainage systems and sanitation systems; in rural areas, floods have affected unpaved roads, man-made slopes, and the ability to use heavy machines on plantations and pastures.

Zones 2 and 8 experienced the greatest economic, social and environmental losses and disasters that killed hundreds of people. Based on the population distribution (Fig. 3), both zones occupy 80% of the areas with more than 50 inhabitants per km^2. These zones are associated with the climatic conditions (Fig. 2) in which rainfall reaches values as much as 4,500 mm/year and can occur throughout the year. Eighteen of the large cities cited in Table 3 and more than a dozen of the cities considered in Table 3 are located in these zones, including the metropolitan regions of São Paulo, Rio de Janeiro, Belo Horizonte, Curitiba and Porto Alegre. In these zones, disasters appear to have been primarily caused by natural and man-made hazards over the past 25 years.

Considering the distribution of the hazards and the frequency of the disasters found in the eight zones and combined with the population distribution (Fig. 3), we assessed the preliminary direct vulnerability of selected environmental factors (Table 5). The vulnerability assessment was developed considering two characteristic scenarios: (i)

Table 5 - The vulnerability for each hazard and disaster zone considering the environmental elements, population, infrastructure and construction.

Zone	Hazard and degraded land sources	Vulnerability								
		Environmental aspects			Population			Facilities and constructions		
	Vulnerability degree based on hazard types, frequency and intensity	High	Moderate	Low	High	Moderate	Low	High	Moderate	Low
1	Silting	Lakes and Rivers				1*		Water reservoirs		
	Erosion	Landscapes	Rivers			1		Roads		
	Contamination	Surface water	Sediments			1		Water reservoirs		
	Flooding	Lakes and Rivers			3			Build-ings, roads, bridge, dams		
2	Coastal erosion	Beach			2			Buildings, ports	Roads	Pipelines
	Flooding	Rivers, flooding plain			3			Buildings, roads, bridge, dams		
	Gravitational mass move-ments	Relief	Rivers		2			Building, roads	Pipelines	Power lines
3	Erosion	Landscapes	Rivers		1			Roads	Building	
	Silting	Rivers, lakes				1		Water reservoirs		
	Contamination	Groundwater	Soil		1				Industries	
4	Contamination	Groundwater	Superficial water		2			Industries		
	Desertification	Landscapes	Rivers, lakes		1			Agriculture		
	Erosion	Landscapes, rivers				1		Pastures	Cultivations	
	Groundwater lowering	Groundwater, springs			2			Industries		
5	Erosion	Landscape, rivers	Lakes			1			Roads, buildings	
	Desertification	Rivers, landscape			1			Agriculture		
	Streambank erosion	Rivers	Lakes ,reservoirs			1		Fluvial transporta-tion, bridges, ports	Buildings, pipe-lines, roads	
	Flooding	Floodplains			3			Buildings, ports	Roads	
6	Earthquakes						1			Buildings, roads, dams
7	Desertification	Superficial and groundwater, soil fertility			2			Cultivations	Buildings	Roads
8	Sinkholes	Groundwater				2		Buildings, roads	Pipelines	
	Depressions (uvalas and others)	Groundwater and surface water				1		Buildings, roads		

Table 5 (cont.)

Zone	Hazard and degraded land sources	Vulnerability								
		Environmental aspects			Population			Facilities and constructions		
	Vulnerability degree based on hazard types, frequency and intensity	High	Moderate	Low	High	Moderate	Low	High	Moderate	Low
	Caverns	Groundwater				1		Buildings, roads		
	Contamination	Groundwater			2			Industries		
9	Gravitational mass movement	Relief, rivers			3			Building, roads	Pipelines, power lines	
	Erosion	Rivers				1		Roads	Pipelines	Power lines
	Flooding	Rivers, flooding plain			3			Building, roads	Pipelines	Power lines
	Tailing dam ruptures	Rivers				1		Bridges, cultivations		
	Uncontrolled sanitary landfills	Groundwater	Surface water, soil			1			Water reservoirs	

Legend: 1* - magnitude of the vulnerable people.

based on the distribution of the hazards in the 8 zones and considering the possibilities of the most important natural components, construction and infrastructure factors, which resulted in a classification involving high, moderate and low vulnerability levels; and (ii) based only on the population to determine the specific vulnerability of the people related to specific hazard types based on the population and density distribution. The latter analysis was used to evaluate the magnitude of vulnerable people in each zone. Three levels were used, from 1 (low magnitude) to 3 (high magnitude), according to item 10 of the materials and methods section.

9. Conclusions

Brazil urgently needs governmental legislation for the creation of an organization responsible for territorial planning, including geological and geotechnical studies on hazard forecasting, with the objective of avoiding disasters and decreasing the associated economic, social, human and environmental losses.

Between 2008 and 2012, at least 400 disasters occurred in Brazil, generating high economic and social losses, affecting more than 10 million people and killing more than 3,000 people. However, only a few events were recorded, either in the EM-DAT database or in the Brazilian databases.

The inventory of this study allowed us to collect a large amount of data on the occurrence of hazards and disasters in Brazil. The eight most affected zones make up more than 40% of the territory of Brazil and consist of more than 70% of the Brazilian population.

Results from this study provide evidence that there is a need for a countrywide policy to forecast these hazards. All Brazilian states experience hazards and disasters, and these hazards are irregularly distributed. Unfortunately, there is a lack of basic knowledge about the environmental factors responsible for such hazards (*e.g.*, rock, unconsolidated materials, geotechnical characterization, climatic behaviors and land uses) in Brazil that is required for a technical understanding of the natural processes that are instrumental in bringing about these dangerous events and disasters.

The hazards and disasters, in terms of their distribution, magnitude and intensity, can be divided into four groups: 1 - hazards of great magnitude and intensity that are responsible for major disasters and economic losses, such as flooding, gravitational mass movements, continental and coastal erosion, subsidence, silting, desertification, tailing dam ruptures, dune movements and drought; 2 - spatially widespread hazards of moderate magnitude and intensity but high economic and social costs (*e.g.*, surface water pollution, saline soils/salinization, groundwater pollution, uncontrolled earth fills, collapsible soils and waste disposal on slopes); 3 - problems registered over smaller areas, such as soil pollution, natural radioactivity, soil liquefaction and expansive geological materials; 4 - occasional problems associated with low economic losses, such as spontaneous fires in peat, dangerous components released in the soil and water, high tides, seismic activities and radioactive spills.

The coastal zone (Zone 2) and mountain zone (Zone 8) are the most affected by disasters originating from gravitational mass movements, flooding, subsidence, tailing dams, sanitary landfills and erosional processes. The states most affected by such hazards, disasters and land degradation are Santa Catarina, São Paulo, Rio de Janeiro, Paraná, Pernambuco and Minas Gerais. The disasters have occurred in these zones at a frequency of once every 5 years and are associated with significant economic (500,000 USD) and social losses (damage to houses and infrastructure). Some urban areas in these zones experience disasters on an annual basis, whereas disasters due to gravitational mass movements occur once every 5 years in these areas.

Erosion, collapsible soils and silting are the common problems encountered in the regions classified as zones 1 and 3. There are rare fatalities associated with these events, but the economic and environmental costs can be significant and pertain largely to restoration and mitigation efforts. The rivers, lakes and reservoirs are very vulnerable, and people suffer from the indirect effects associated with human, industrial and livestock water requirements.

Zone 4 comprises the recharge areas of the main aquifer in Brazil. This zone is affected by contamination, and the groundwater level has lowered over time. In the long term, the problems inherent to this zone will limit groundwater exploitation, and hundreds of urban areas will suffer greatly as a result. In addition, there are changes in the nature of water infiltration from the ground surface because of agriculture and urbanization.

Zone 5 is intensely affected in terms of the associated environmental losses because of overcultivation and overgrazing, resulting in major changes to the natural condition of the geological materials, water dynamics and relief.

Annually, Brazil loses more than 1,000 people and 2 billion USD due to disasters originating from natural hazards, and Brazil has spent less than 10% of this amount on the forecasting of hazards and in adopting measures to minimize deaths and economic, social and environmental losses.

The spatio-temporal distribution of the triggering events does not follow a defined pattern in terms of trends or regional behavior, although the events are strongly related to geological and geotechnical aspects. Although hazards are distributed throughout the country, those involving gravitational mass movements, flooding and erosional processes deserve special attention because they are responsible for a significant portion of the economic and social losses. Gravitational mass movements occur mainly in areas with unconsolidated residual or transported materials overlying igneous and metamorphic terrane. Although laminar erosion has stabilized in the country since the adoption of improved agricultural management practices, the number of rills and gullies has increased significantly due to the redirection of superficial water flow. Studies of hazard forecasting that includes the mapping of hazard areas should be developed to make more informed disaster management plans.

The results of the inventory and analyses verify that there is an urgent need to develop systematic programs for specific geological and geotechnical research. These programs can develop engineering geological maps to support the elaboration of hazard maps and thus prepare adequate risk charts. These maps will provide fundamental information about the geological and geotechnical background of a region and the distribution of the hazard types and disasters in Brazil so that governmental institutions can adopt measures to control and avoid disasters caused by hazards.

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