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LANDSLIDES IN THE STATE OF PERNAMBUCO

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Abstract

Even though the occurrences of social and economic losses and fatal victims caused by landslides in Pernambuco are recurrent, one must consider that there is a gap in the systematization of information pertaining to such processes in a georeferenced spatial database at a state level, especially with regard to the location and types of triggering conditioning factors. This work is intended to evaluate the occurrence of landslides in the state of Pernambuco, the conditioning factors thereof, and the most affected areas. For such, a Geographic Database (Banco de Dados Geográfico - BDG) and an inventory map were created, based on the capture of landslides in the state between 1988 and 2019, both through secondary and primary sources. Lastly, all of the occurrences were catalogued in information plans, vectorized in a GIS (Geographic Information System) environment and correlated with thematic variables of the main conditioning factors. 3,138 landslides in Pernambuco were inventoried, which enabled the verification of behavior patterns regarding the occurrence of said processes in the state. The formation of this georeferenced spatial database may contribute to better understand the incidence of these processes, and thus subsidize the establishment of investigative methodologies and strategies related to the subject.

Keywords: Inventory; Database; Mass Movements; Northeastern Brazil.

Resumo / Resumen

ESCORREGAMENTOS NO ESTADO DE PERNAMBUCO

Embora sejam recorrentes as ocorrências de perdas sociais, econômicas e vítimas fatais causadas por escorregamentos em Pernambuco, há de se considerar que existe uma lacuna quanto à sistematização de informações relativas a estes processos em uma base espacial georreferenciada na escala estadual, principalmente, quanto à localização e aos tipos de fatores condicionantes deflagradores. O objetivo do presente trabalho consiste em avaliar a ocorrência de escorregamentos no estado de Pernambuco, seus fatores condicionantes e áreas mais atingidas. Para tanto, foi elaborado um Banco de Dados Geográfico (BDG) e mapa de inventário a partir da captura de escorregamentos no estado, entre 1988 e 2019, tanto por meio de fontes secundárias quanto primárias. Por fim, todas as ocorrências foram catalogadas em planos de informação, vetorizadas em ambiente SIG (Sistema de Informações Geográficas) e correlacionadas com variáveis temáticas dos principais fatores condicionantes. Foram inventariados 3.138 escorregamentos em Pernambuco, que permitiram a verificação de padrões de comportamento quanto à ocorrência destes processos no estado. A formação dessa base espacial georreferenciada poderá contribuir no melhor conhecimento sobre a incidência destes processos e, assim, subsidiar o estabelecimento de metodologias e estratégias investigativas relacionadas a esta temática.

Palavras-chave: Inventário; Banco de Dados; Movimentos de Massa; Nordeste do Brasil.

DESLIZAMIENTOS EN EL ESTADO DE PERNAMBUCO

Aunque son recurrentes las ocurrencias de pérdidas sociales, económicas y víctimas fatales por deslizamientos de tierra en Pernambuco, se debe considerar que existe un vacío en la sistematización de la información relacionada con estos procesos en una base espacial georreferenciada a escala estatal, principalmente en lo que se refiere a la ubicación y los tipos de factores condicionantes desencadenantes. El objetivo de este trabajo es evaluar la ocurrencia de deslizamientos de tierra en el estado de Pernambuco, sus condicionantes y las áreas más afectadas. Para eso, se creó una Base de Datos Geográfica (BDG) y un mapa de inventario a partir de la captura de deslizamientos de tierra en el estado entre 1988 y 2019, tanto a través de fuentes secundarias como primarias. Finalmente, todas las ocurrencias fueron catalogadas en planes de información, vectorizadas en un ambiente SIG (Sistema de Información Geográfica) y correlacionadas con variables temáticas de los principales condicionantes. En Pernambuco se inventariaron un total de 3,138 deslizamientos de tierra, lo que permitió verificar patrones de comportamiento ante la ocurrencia de estos procesos en el estado. La formación de esta base espacial georreferenciada puede contribuir a una mejor comprensión de la incidencia de estos procesos y, así, subsidiar el establecimiento de metodologías y estrategias de investigación relacionadas con esta temática.

Palabras-clave: Inventario; Banco de datos; Movimientos de Masas; Nordeste de Brasil.

INTRODUCTION

The swift urbanization of developing countries contributed to the proliferation of housing on steep slopes, especially in an improper manner, intensifying the occurrence of landslides, resulting in the expansion of risk areas and causing the destruction of houses with several economic damages and fatal victims (AYALA, 2002; NATENZON and RÍOS, 2015; LISTO et al., 2021). In Brazil alone, a population of approximately 8,266,000 inhabitants in landslide and flood risk areas is estimated, in 825 towns in the country (IBGE, 2018a; ALVALÁ et al., 2019).

In Northeastern Brazil, in general lines, the states of Pernambuco and Bahia stand out with regard to the deflagration of mass movements. Together, both concentrate 89.5% of these processes since 1991 (CEPED/UFSC, 2013; SANTOS et al., 2018). Within such context, Pernambuco presents a longitudinal variety of land usages and occupations, very influenced by geomorphological and climatic issues. The state has a variety of landscapes and environmental contrasts, the morphodynamic processes of which, especially erosions and landslides, widely affect the entire territory, both in humid and semiarid areas. In the Recife Metropolitan Region (RMR) alone, for example, the cities of Recife, Jaboatão dos Guararapes, Ipojuca and Igarassu are located among the 10 cities with the highest percentage of the population residing in landslide risk areas in Brazil, where there are several housing areas precariously installed in susceptible plots of land (IBGE, 2018a).

Even though social and economic losses and fatal victims caused by landslides are recurrent in Pernambuco, one must consider that there is a gap in the systematization of information pertaining to such processes in a georeferenced spatial database at a state level, especially with regard to the location and types of triggering conditioning factors. However, this type of database allows analyses to be made to better understand the problem, enabling the creation of predictive models. Furthermore, it facilitates territorial ordering and planning and the minimization of losses due to catastrophic processes, among other benefits like the standardization of information and monitoring, prediction and warning systems.

The construction of a database for mass movements, including landslides, must consider the purpose thereof and the extent of the relevant area, which in turn defines the collection techniques and the overall quality of the data (GUZZETTI et al., 2000; GUZZETTI et al., 2012). Databases at global and continental scales are usually intended to evaluate the impact of landslides, prioritizing information such as type and magnitude of the event, number of victims, damages to the society, among others, usually with less time and space accuracy.

Approximations of global inventories integrated into databases could be seen in the works by Kirschbaum et al. (2010) and Kirschbaum, Stanley and Zhou (2015). The former sought to describe a methodology to catalogue landslides in a systematic manner (global scale) using media information, as well as real-time reports from the years of 2003, 2007 and 2008 with processes recorded in 44, 60 and 67 countries, respectively (KIRSCHBAUM et al., 2010). In turn, Kirschbaum, Stanley and Zhou (2015) created a Global Landslide Catalog, for landslides triggered by intense rainfall from 2007 to 2013, with data from media reports, secondary databases, scientific productions, among others. Said catalog gathered 5,741 occurrences of landslides, divided into events with and without casualties, in 124 countries and territories (KIRSCHBAUM, STANLEY and ZHOU, 2015).

At a national scale, we highlight the works by Pereira et al. (2014) in Northern Portugal (Northern Portugal landslide database), with records from 1900 to 2010; by Pennington et al. (2015) based on the creation of Britain's National Landslide Database, containing over 17,000 records of landslides in natural and artificial slopes, and the works by Calvello and Pecoraro (2018), titled FraneItalia (landslides in Italy), which used media information from 2010 to 2017. These works collected, in general lines, a greater quantity of information from media and scholarly sources, such as start and duration of the landslides, process characteristics, consequences, among others. In general, they have a better time accuracy, but are more inaccurate as to the location and geometry of the events with regard to details.

In Brazil, the National Center for Risk and Disaster Management (Centro Nacional de Gerenciamento de Riscos e Desastres - CENAD) created the Integrated System of Information on Disasters (Sistema Integrado de Informações sobre Desastres - S2iD) in 2012, intended to improve the management of strategic actions, preparation and response to disasters within the Brazilian territory. The system concentrates, at a federal level, information on disasters, among which 36 landslides were recorded in Pernambuco. Also in this regard, the University Center of Disaster Study and Research

(Centro Universitário de Estudos e Pesquisas sobre Desastres - CEPED) of the Federal University of Santa Catarina (UFSC) produced the Brazilian Atlas of Natural Disasters from 1991 to 2012 (CEPED/UFSC, 2013). It recorded 24 landslides throughout the state of Pernambuco in the period evaluated. Local initiatives must also be mentioned, especially those derived from the databases of the Municipal Civil Defenses, such as those of the cities of Recife and Jaboatão dos Guararapes (RMR/PE), which annually record landslides (date of occurrence, address, description of the event and actions of monitoring, removal and/or closing off of dwellings).

Galli et al. (2008), Kirschbaum et al. (2010), Parise (2001), Guzzetti et al. (2012), Pereira et al. (2014) and Calvello and Pecoraro (2018) stress that databases can be prepared for multiple scopes: (i) documenting the extent of the processes; (ii) investigating their distribution, types and patterns in relation to the morphological and geological characteristics; (iii) enabling a better understanding of the evolution of the landscapes dominated by processes; and (iv) being a preliminary stage to the evaluations of susceptibility, danger and risk, which are essential for a better decision-making and for the ordering and planning of human actions in the territory. Most times they are usually associated with GIS (Geographic Information System), constituting a Georeferenced Database (BDG), gathering geoenvironmental information, such as elevation, declivity, geology, pedological cover and land use (agents that trigger the landslides). This type of collection enables the spatial evaluation of the phenomenon within different environmental contexts, assisting with the identification of occurrences and, consequently, with locating the areas where monitoring is a priority. Thus, this work is intended to evaluate the occurrence of landslides in the state of Pernambuco, the conditioning factors thereof and most affected areas.

STUDY AREA: STATE OF PERNAMBUCO

Pernambuco is entirely located within the intertropical zone and has maximum altitudes of 1,200 m (Figure 1). It has an area of 98,068 km² and a population of 8,796,000 inhabitants, with greater population density in the areas close to the coast (especially the RMR) due to its historic and economic formation (ARAÚJO FILHO et al., 2000; ANDRADE, 2007; CEPED/UFSC, 2013; IBGE, 2018b).

It is predominantly located on precambrian igneous and metamorphic rocks, belonging to the São Francisco Craton and the Borborema Province (e.g. Granite and Granodiorite), which occupy 90% of its territory. The other sectors are formed by interior paleo-mesozoic sedimentary rocks (e.g. Sandstone, Shale and Siltstone) and meso-cenozoic coastal sedimentary basins (CPRM, 2001; ANDRADE, 2007; FERREIRA; DANTAS and SHINZATO, 2014).

The relief is the result of the evolution of geological and geomorphological events, associated with the opening of the Atlantic Ocean during the Cretaceous period. Ferreira, Dantas and Shinzato (2014) note nine great geomorphological domains in Pernambuco: Coastal Plain, Coastal Tablelands (Coastal Sedimentary Plateau), Borborema Piedmont, Borborema Plateau, Sertaneja Depression, Araripe Flatland, Jatobá Basin, São Francisco River Plain and groups of Countryside Sedimentary Basins.

There are at least three mesoclimate types associated with humid (total annual pluviometric measurements from 800 mm to 2,000 mm), semi-humid (from 600 mm to 800 mm) and semiarid environments (total pluviometric measurements lower than 600 mm, on average) (FERREIRA and MELLO, 2005). The humid sectors of Pernambuco extend between the Coastal Plain and the eastern sector of the Borborema Plateau, while the sub-humid sectors are located on the Borborema Plateau, and lastly the semi-arid sectors are located, for the most part, in the Sertaneja Depression, even though they appear on the highlands of the Borborema Plateau.

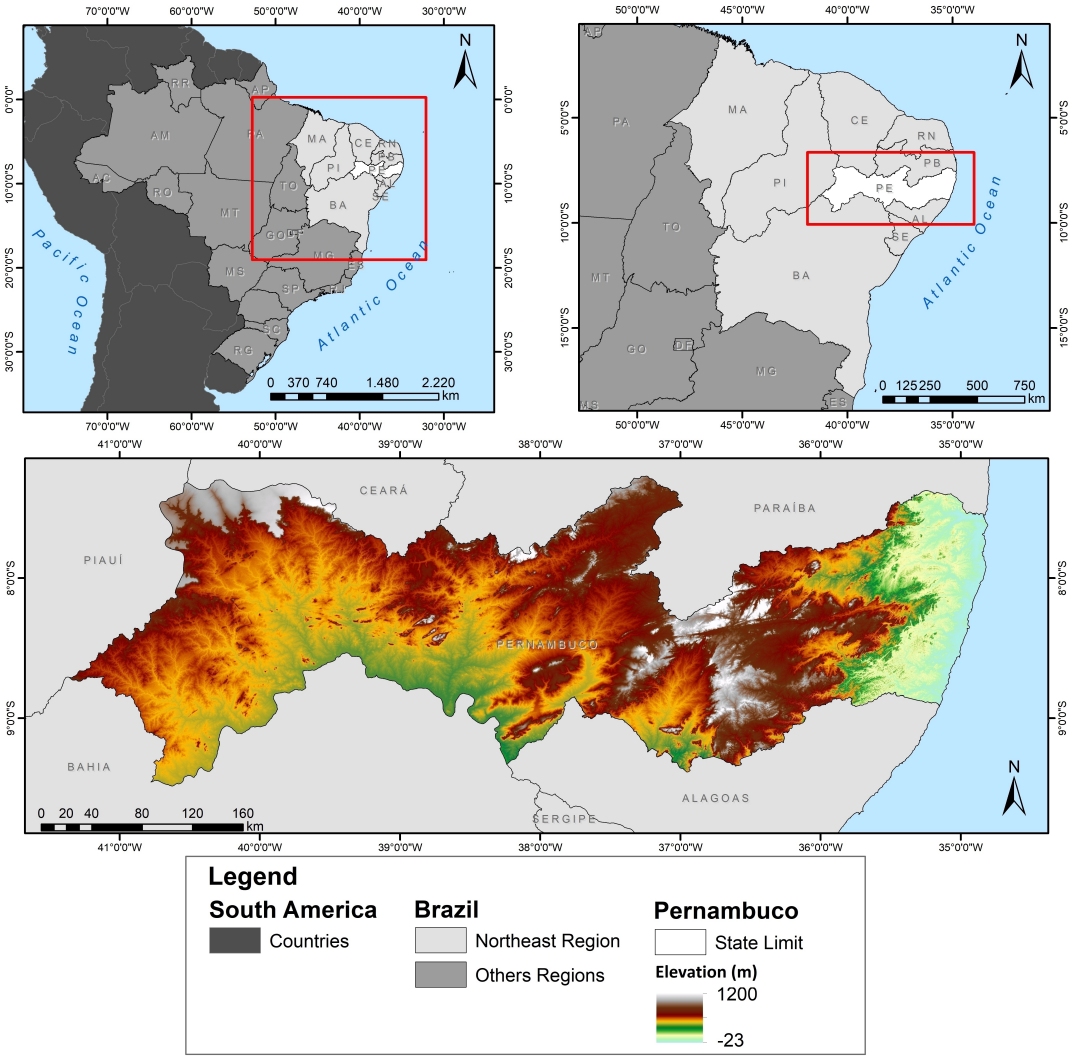

Figure 1 - Location and hypsometry map of the study area (state of Pernambuco). Source: Authors. Database: Nasa Earth Data.

Studies point to a positive correlation between the climate difference and the geomorphology of Pernambuco, especially the interface between rainfall and the altitude in the backlands of the state (ALBUQUERQUE et al., 2019). Molion and Bernardo (2002) and Ferreira and Melo (2005) note precipitation mechanisms at macro, meso and microscale. From the macroscale mechanisms, those that stand out are the frontal systems and the Intertropical Convergence Zone (ITCZ). At mesoscale, the wave disturbances in trade winds (Easterly Wave Disturbances/EWDs) stand out, which are responsible for torrential rainfall that deflagrate mass movements, convective complexes and sea and land breezes. At microscale, orographic circulations and small convection cells occur (MOLION and BERNARDO, 2002; FERREIRA and MELLO, 2005).

Girão et al. (2006) had already verified that for the Recife Metropolitan Region (RMR), for example, the most intense pluviometric totals derive from supplemental synoptic systems, from which the easterly wave systems (barometric troughs) stand out. These promptly affect the urban slopes of the RMR and work as triggers that induce the activation (or reactivation) of landslides in the forms sculpted on the Barreiras Formation (GIRÃO et al., 2006). Thus, the RMR slopes present a high potential instability, due to the succession of erosive processes and landslides on the Miocene covers of said formation, potentialized by the anthropized areas (ALHEIROS and AUGUSTO FILHO, 1997; SANTANA and LISTO, 2018).

In the domain of the Plain and the Coastal Tablelands, partly entering the Borborema Piedmont, the largest population contingent of Pernambuco (around four million people) is located, in which the

RMR is one of the largest metropolitan regions in Brazil. In this sector, the main economic hub of the state, the Suape Industrial Port Complex, is located (FERREIRA; DANTAS and SHINZATO, 2014). However, historically speaking the landslide processes occur more frequently within the domain of the Tablelands, especially due to the interface between the more intense rainfall and the precariously occupied structure of sedimentary rocks and tabular forms or dissected hills of the RMR (ALHEIROS and AUGUSTO FILHO, 1997). The social injustices derived from the patterns of usage, occupation and planning of its urban sites also stand out, which have led to the occupation of improper areas by more vulnerable populations.

MATERIALS AND METHODS

THEORETICAL BASES AND CREATION OF THE INVENTORY MAP

The theoretical bases for the creation of the inventory followed international procedures in the construction thereof, pursuant to Guzzetti et al. (2000). Said authors divided these types of mapping into two categories: (i) archive and (ii) geomorphological. The former pertains to data surveying methods by means of archives and records of other sources, such as national or global databases, newspapers and magazines, technical reports and academic productions. The latter is associated with the surveying of primary data and can be produced for a single triggering event (e.g. a storm) or show the accumulated effects of several events during a set period (PARISE, 2001; MALAMUD et al., 2004; OLIVEIRA, 2012; PEREIRA et al., 2014; KIRSCHBAUM; STANLEY and ZHOU, 2015; CALVELLO and PECORARO, 2018).

Pursuant to Guzzetti et al. (2000; 2012), each technique is associated to the purpose and extent of the study area (scale), the resolution, the characteristics of the available data, the resources and the surveyor's experience. Galli et al. (2008) report that the use of more than one technique is frequently used, such as an association between archive surveying, photo-interpretation of satellite images and fieldwork. In this regard, the work complied with the presuppositions related to the archive type, considering the scale of the study area (minor detail), also associated with primary sources (e.g. obtainment of field data and interpretation of satellite images). Therefore, the survey and the capture of landslide occurrences available for the continental territory of Pernambuco were made, in the 1988-2019 time series.

As to the primary data, ten exploratory fieldworks for the georeferencing of the landslide scars were carried out between 2017 and 2019. They encompassed towns in the Recife Metropolitan Region (e.g. Recife, Ipojuca and Camaragibe), Coastal Forest (e.g. Quipapá, Palmares and Aliança), Countryside (e.g. Guaranhuns and Gravatá) and Pernambuco Backlands (e.g. Triunfo, Santa Cruz da Baixa Verde, Exu, among others).

The satellite images used to interpret and locate the landslides were taken from the databases of software Google Earth Pro (LANDSAT 90º or vertical). The scars were identified according to the criteria indicated by Guzzetti et al. (2000; 2012), such as geometry of the processes, elongated aspect, differences in color and texture, absence of vegetation and their position on the slope (Figure 2).

Several occurrences were also catalogued based on secondary sources, such as: (i) scholarly works (congress annals, periodical articles, books, dissertations and theses) researched online in platforms Google Scholar and Periódicos CAPES; (ii) technical reports from public institutions, such as the Brazilian Center for Risk and Disaster Management (Centro Nacional de Gerenciamento de Riscos e Desastres - CENAD), Brazilian Center for Natural Disaster Monitoring and Alerts (Centro Nacional de Monitoramento e Alerta de Desastres Naturais - CEMADEN), Mineral Resources Research Company (Companhia de Pesquisa de Recursos Minerais - CPRM), among others; (iii) databases provided by the Local Civil Defense Coordinations (Coordenadorias Municipais de Defesa Civil - COMDEC) and (iv) newspaper articles. The media (newspaper) information was obtained from consulting and sweeping the online databases and those of the Pernambuco Public Archive, from 1988 to 2019, of the main media outlets of the state (and some of national circulation), such as Portal de Notícias G1, Jornal O Globo, Diário de Pernambuco and Jornal do Commercio (Recife/Grupo JCPM), in order to collect news about

landslides in the state.

Figure 2 - Example of a satellite image used to locate the landslide scar on the south escarpment of the Araripe Flatland (town of Exu, semi-arid region of Pernambuco). Source: Database of software Google Earth Pro (2018).

To record all of the occurrences, the data collected, either through primary or secondary sources, needed to contain at least the location in a coordinate pair or location information that could be georeferenced in a GIS environment (e.g. address or approximate location).

CREATION OF THE GEOREFERENCED DATABASE

As per the previous stage, the landslide occurrences were geocoded and represented by point-type vectors, considering the scale of the Database (state), which prevented the representation by polygon-type vectors. The use of the GIS environment enabled the creation of the occurrence map for Pernambuco with a legend compatible with the GDB information plans.

At this stage, in addition to the information related to the process codes and their coordinates (Table 1), other data of a themed nature/information plans were added (e.g. geology, declivity, soils, among others), which were relevant when related to the occurrence maps/inventories (Table 1). This information was stored in vertical format in the GDB, enabling the overlapping with the inventories and the analysis of the main conditioning factors and damages caused.

The GDB was thus intended to store relevant information for analysis of the processes in Pernambuco, the conditioning factors thereof and the most affected areas, created by joining the abovementioned themed data and the location thereof in occurrence maps. Therefore, all of the data were stored in a GIS environment (tables of attributes and information plans), thus completing the Georeferenced Database.

Category	Mandatory Datum	Source	Example	Importance/Meaning
Process Code	Yes	Research result	Landslide (ES0273)	The code assigned to each occurrence has the following structure: the first two letters are the process initials (e.g. Landslide [*Landslide*] - ES) and the numbering represents the cataloguing sequence (e.g: first landslide catalogued as ES0001; thousandth landslide catalogued as ES1000), and so on.
Process	Yes	Field, satellite images and secondary bibliographical references	Landslide	Inventory of the landslides by occurrences.
Coordinates	Yes	GPS Surveying and GIS Geocoding	08° 03′ 14″ S 34° 52′ 51″ W	Georeferencing of the occurrences.
City	Yes	IBGE (2018b)	Recife	Official outline of the limits of the state of Pernambuco and its cities.
Process Classification	No	Field and secondary bibliographical references	Shallow Translational Landslide	Classification was not a mandatory parameter for this inventory, with regard to the typologies of the landslides (translational, rotational or wedge). The processes were classified only with regard to their main typology (landslide).
Date of occurrence	Yes*	Field and secondary bibliographical references	06/13/2019	Cataloguing the month of occurrence, whenever possible, was relevant to relate it to the pluviometric parameters.
Elevation	Yes	SRTM and PE3d	80 meters	Extraction of altitude and declivity information, as well as other topographic parameters.
Declivity	Yes	SRTM and PE3d	11.8°	Increase of the speed of surface flow and movement of surface materials.
Geology	Yes	CPRM (2001)	Barrier Formation	Different mineralogies, degrees of weathering with distinct susceptibilities.
Soils	Yes	Silva *et al.* (2001)	Acrisol	Morphogenesis/pedogenesis ratio and its stability conditions.
Land use and occupation	Yes	IBGE (2018c)	Residential	Anthropogenic pressures responsible for potentializing and deflagrating the processes.
Damages	No	Field and secondary bibliographical references	Death	Number of victims and social and economic losses.

Table 1 - Summary of variables (database) and descriptions thereof.

RESULTS AND DISCUSSIONS

3,138 landslides were inventoried, between 1988 and 2019, for the state of Pernambuco (Figure 3). The catalogued processes were located, in their majority, in the Recife Metropolitan Region and in the South Coastal Forest of Pernambuco (with around 98% of the landslides) (Figure 4). They occasionally occurred in the Countryside and Backlands of Pernambuco (Figure 5).

Out of these, 74% were concentrated on the Borborema Piedmont covered by Open Ombrophilous Forest and hot humid tropical climate (3 dry months), especially in the town of Jaboatão dos Guararapes (RMR). Said areas are characterized by crystalline geology, with forms that are predominantly hilly and steep with convex tops, favoring the detachment of the material of the slopes.

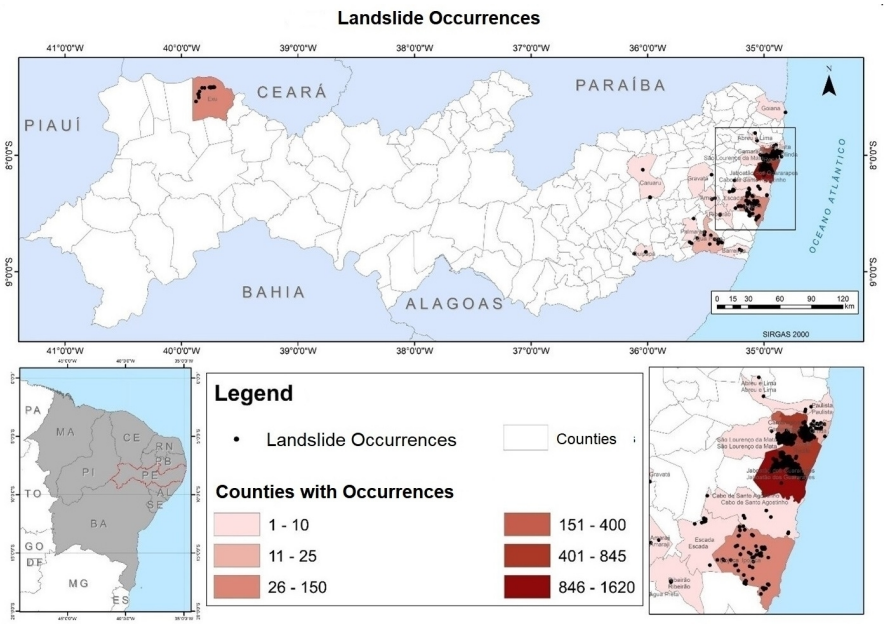

Figure 3 - Map of landslide occurrences (inventory) for the state of Pernambuco. Source: Authors.

Figure 4 - Examples of landslides occurred in the Recife Metropolitan Region (RMR): (A) Landslide ES0223 in the town of Camaragibe, (B) Landslide ES0369 also in the town of Camaragibe and (C) Landslide ES3125 in the northern zone of the city of Recife, in all of which the occurrence of the processes is observed in precariously installed areas, with great social and economic losses. Sources: (A) Newspaper Diário de Pernambuco (2015), (B) Website Portal G1 PE (2019) and (C) Newspaper Diário de Pernambuco (2015).

Figure 5 - Landslide ES0409 at the southern escarpment of the Araripe Flatland (town of Exu), semi-arid region of the state of Pernambuco. Source: Authors (2018).

Furthermore, 14% of the processes were located at the Coastal Tablelands with Open Ombrophilous Forest and hot humid tropical climate (3 dry months), as well as in the town of Paudalho (Southern Coastal Forest) and in the city of Recife (RMR). This is a unit with sedimentary geology (Barreiras Formation) more susceptible to shear, especially when there are great pluviometric volumes due to the action of sea and continental breezes and the Easterly Wave Disturbances. Moreover, they are precariously occupied areas (areas under risk of landslides), with several conditions of physical and social vulnerability (e.g. technically incorrect cuts and landfills; disposal of wastewater directly onto the slope; excess garbage and debris; dwellings very close to the base and the top of the slopes), in addition to removal of the vegetation cover.

In the landslide and months of the year ratio (Figure 6), a greater concentration between April and July is noted, as they are periods with a higher rate of rainfall at the coast of Pernambuco, the rain volume of which is higher between autumn and winter. The summer rains, despite their short duration, also usually cause landslides, since they have sufficient energy to detach susceptible masses, especially in the more anthropized (potentially unstable) environment.

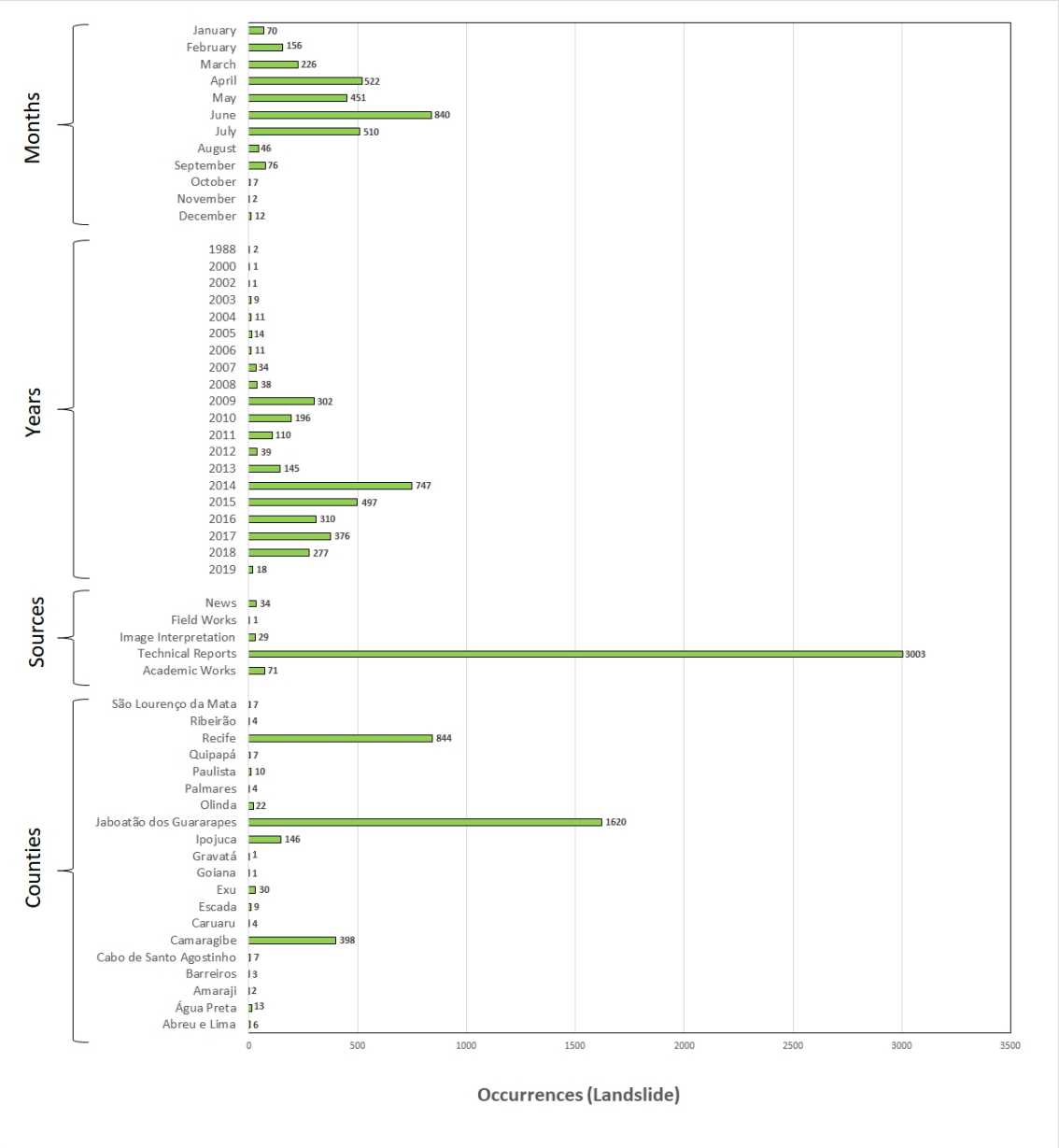

Figure 6 - Database evidencing the number of landslides per information plane (part one). Source: Authors.

With regard to the time series (years), the landslides increased, especially from 2009 (Figure 6), when the Civil Defense forces started to keep records. This gradual increase is related not only to the greater population density, and thus anthropic interference through the establishment of precariously installed housing areas, but also to the greater frequency of official records, especially from the Municipal Civil Defense forces.

Regarding the sources used, 3,003 landslides (95%) were acquired through technical reports (e.g. databases provided by the Municipal Civil Defense forces of Camaragibe, Jaboatão dos Guararapes and Recife and by CEMADEN), in addition to CPRM (BITAR, 2014) and SINPDEC (2019) (Figure 6). Seventy-one occurrences were taken from the academic work done by Torres (2014), who mapped out landslides in the town of Ipojuca, at the southern coast of the state (RMR) (Figure 6).

Twenty-nine landslides were catalogued by interpreting satellite images, restricted to the escarpment of the south flank of the Araripe Flatland (clearness of the process in a semi-arid environment with few clouds, vegetation and no significant anthropic interference), in addition to validation through fieldwork (Figure 6). Out of the media sources, 16 occurrences were taken from

Jornal Diário de Pernambuco, 12 from Portal G1, 5 from Jornal do Commercio and 1 occurrence from Jornal O Globo, totaling 34 landslides obtained from this type of source (Figure 6). News articles were important consultation sources, mainly due to the wealth of details concerning the losses and the economic and social damages in the urban areas (Figure 4).

The most affected cities were those in the RMR, such as Jaboatão dos Guararapes (1620 landslides), Recife (844), Camaragibe (398), Ipojuca (146), Olinda (22) and Paulista (10 landslides) (Figure 6). The RMR area of influence is characterized by an accelerated urban expansion to lands of Cenozoic sedimentation, which are more susceptible to morphodynamic processes (FERREIRA; DANTAS and SHINZATO, 2014). A large part of the Recife hills was occupied by populations of lower social class, due to the appropriation by the real estate market of areas more favorable to building, increasing the number of at-risk areas (ALHEIROS, 1998; PFALTZGRAFF, 2007; XAVIER et al., 2019). This type of occupation often occurs with precarious structures, increasing the instability of steep slopes characterized by the accumulation glacis of the Barreiras Formation (ALHEIROS, 1998; PFALTZGRAFF, 2007; SANTANA and LISTO, 2018; XAVIER et al., 2019).

In this regard, anthropic interference in the RMR has been changing the topography and the hydrological dynamic of the slopes by creating levels and ruptures through cuts, in addition to the unsettlement of indiscriminate materials in landfills, done by the local population, which are common in the risk areas. Said interferences take on an important role in the deflagration of landslides due to increased instability and absence of geotechnical works of protection. In addition, the occupation created artificial knickpoints, which changed the equilibrium profile of the slopes and generated artificial embankments with declivities that are incompatible with the angle of repose of the materials that structured said relief (incohesive sediments of the Barreiras Formation) (SANTANA and LISTO, 2018).

Beyond the bounds of the RMR, the town of Exu stands out (30 landslides), which town is located at the southern flank of the Araripe Flatlands (semi-arid region of Pernambuco) (Figure 5 and Figure 6). Said occurrences are located on steep escarpments of said flatlands, of a sedimentary structure, which is more susceptible to landslides, the pluviometric events of which (more restricted) occur due to the effects of the ITCZ (Intertropical Convergence Zone) and the High-Level Cyclonic Vortexes.

With regard to the geology (Figure 7), the lithologies of the Barreiras Formation (fine and thick sandstones) concentrate the highest number of landslides with 1323 occurrences, mostly in the Coastal Sedimentary Plateau (Tablelands) of the RMR. The crystalline lithologies (e.g. amphibolite) of the Borborema Piedmont also stand out, with 1114 occurrences (Figure 7).

In the declivity parameter, the landslides were located, as expected, in the steepest areas, especially in the strongly undulated (11.3º and 24.2º) and mountainous (24.2º and 36.9º) classes, respectively, with 1,742 and 1,160 occurrences (Figure 7), which matches the results found in Gao (1993), Montgomery and Dietrich (1994), Alheiros and Augusto Filho (1997), D'Amato Avanzi et al. (2004), Fernandes et al. (2004), Listo and Vieira (2012) and Santana and Listo (2018). These areas coincide with the slopes of the Borborema Piedmont and the Coastal Tablelands, which in the past were originally covered by Seasonally Dry Forests and Ombrophilous Forests, typical of the Atlantic Forest.

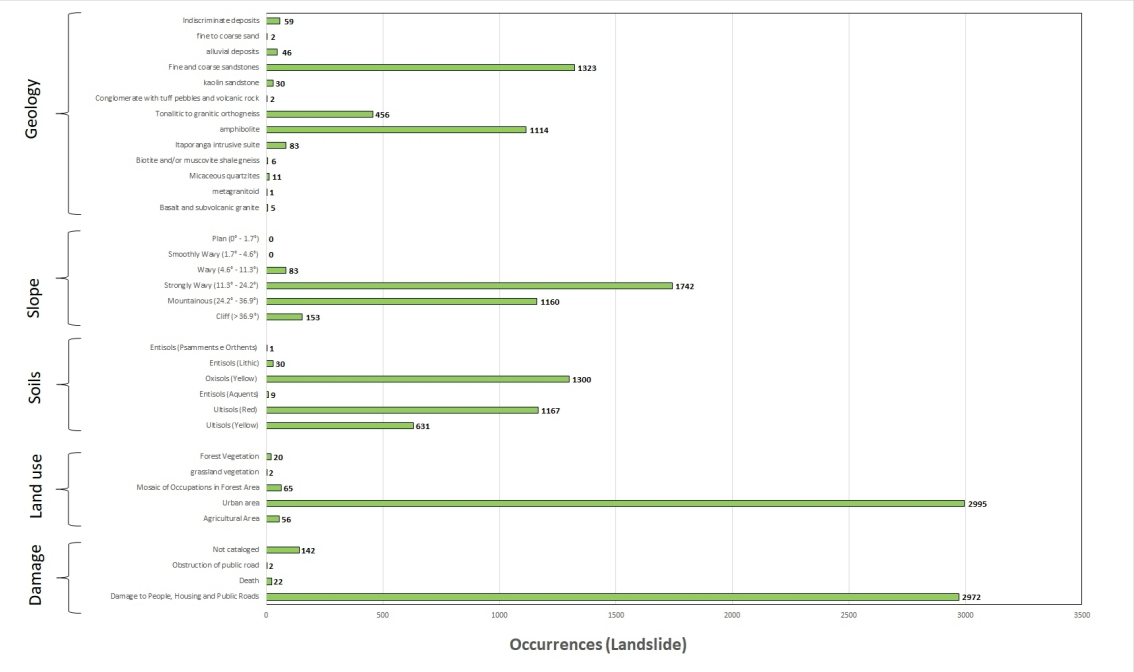

Figure 7 - Database evidencing the number of landslides per information plane (part one). Source: Authors.

However, said covers were practically devastated by the settlement that began in the 16th century, during the sugarcane planting age. Thus, the remaining forests are restricted to small areas on the tops of hills, and rarely at the bottoms of valleys. These places were taken over for the sugarcane monoculture, which is not usually handled with a conservationist aim (ANDRADE, 2007; FERREIRA; DANTAS and SHINZATO, 2014). Therefore, these are highly anthropized environments with declivities that vary between strongly undulated and steep (at the edge of the tablelands). They thus have a greater likelihood of landslides triggered by torrential rainfall in events that derive from wave disturbances in trade winds, convective complexes and sea and land breezes.

In relation to the soils, the yellow latosols (1300 occurrences), red acrisols (1167) and yellow acrisols (631) stand out, all of which are very susceptible (Figure 7). The clay increment in the textural horizon B of the acrisol hinders water infiltration, but it saturates the upper layers, which come loose and slip down to the base level. The latosols, in turn, present structures that favor infiltration and, once saturated, break off (SIDLE; PEARCE and O'LOUGHLIN, 1985; DIAS and HERRMANN, 2002).

Approximately 95% of the landslides are located in urban areas (2995 occurrences) (Figure 7), reinforcing the greater incidence of processes conditioned by anthropic parameters in Pernambuco. Consequently, they cause damage to people, houses and public thoroughfares (2972 damages) and casualties (22 catalogued) (Figure 7).

Many authors (e.g. ALHEIROS, 1998; PFALTZGRAFF, 2007; BERLIM; OLIVEIRA and CARVALHO, 2015) attribute the genesis of the landslides in Pernambuco to a natural susceptibility associated with a deficient form of occupation, especially on the Barreiras Formation, present in the RMR. Berlim, Oliveira and Carvalho (2015) also highlight the anthropic interventions incompatible with the dynamic of slopes, such as cuts, diffuse drainage of effluents without sewer systems, cultivation of bananas and other kinds of vegetables that accumulate water, settlement of solid residues and absence of channels for rain outflow, that is, several conditions that increase the landslide risk situations.

CONCLUSION

In the state of Pernambuco, there is a relevant number of technical and scholarly works that refer to landslides, but up until now no attempt to gather occurrences into a single database, in an inter-institutional manner, has been observed. In such scenario, this work used a methodology of

inventory of processes of the archive type, with the surveying of primary and secondary data, to compose the GDB. Thus, 3,138 landslides were catalogued, which surpass past databases with regard to accuracy, information and quantity.

The results pointed to patterns of behavior regarding the occurrence of landslides in Pernambuco. They were concentrated on steep slopes (above 11.3°) of the Borborema Piedmont, based on crystalline lithologies, and on the Coastal Tablelands, on sedimentary rocks, especially from the Barreiras Formation, constituted by latosols and acrisols, at the urban sites of the Recife Metropolitan Region, with severe social and economic damages.

Landslides present in the town of Exu (semiarid) diverge from the environmental context of the other occurrences in the state, because despite being located on sloped ad sedimentary areas (which factors are quite influent over the genesis of the process), they have very little rainfall, since they are located downwind from the Araripe Flatland (southern escarpment) with low anthropic interference. Further studies are necessary to define the triggering events of such occurrences, but certain hypotheses can be raised, such as the deflagration due to simple action by the gravitational potential energy, or also events of extreme precipitation or neotectonic activity.

Georeferenced spatial databases at a state level can guide the strategic decision-making for the public authorities, with regard to the preservation and occupation of new areas, as well as the application of mitigating measures. They also enable a relevant basis for the other forecasting methodologies (letters of susceptibility, vulnerability and risk), in addition to favoring the standardization of data, both for the society and for public institutions. In other words, they enable a qualitative and quantitative (statistical) analysis of the most affected places, and help answer what the main conditioning factors are, benefiting urban and rural planning. Thus, the results of this research are expected to be the first step towards the standardization of landslides in Pernambuco.

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