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Mass movements in the Northeast region of Brazil: a systematic review

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Article

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Abstract
Mass movements are one of the main causes of loss of people and environmental assets. Several factors contribute to mass movements, such as terrain morphology, rainfall regime, soil properties, land use and occupation. Studies showed that in the Northeast region of Brazil, between the years of 1991 and 2012, 38 events related to mass movements were recorded, resulting in 55,963,164 people affected by these events. Based on this information, the aim of this study was to build a systematic review of mass movement and erosion events that occurred in the northeast region of Brazil and were reported in Brazilian academic sources. The research was based on the articles published by the Soils and Rocks Journal and the proceedings of the Brazilian academic events: Brazilian Congress of Soil Mechanics and Geotechnical Engineering, the Brazilian Conference on Slope Stability and the Brazilian Congress of Engineering and Environmental Geology. A survey of all the articles involving the subject matter was conducted between the years of 1954 and 2019 using the key words Landslides, Mass Movements, Geomorphology and Engineering Geology. From the data found, it was possible to identify the main geotechnical characteristics of mass movement occurrences in the region and their causes.

1. Introduction

Slope instabilities, such as erosion, mass transport and mass movements are forms of land degradation and are considered global problems. These processes are the main causes of risk for exposed elements that include people, properties, environmental assets, economic activities, cultural heritage. (Ferlisi & De Chiara, 2016; Guerra et al., 2017).

Slope instabilities along with their spatial/temporal distribution and related consequences differ within a given country and, more in general, from country to country. The slope failures characteristics depend on the specific features of *i*) factors either predisposing to or triggering slope instabilities, *ii*) intensity parameters of hazard scenarios, *iii*) elements at risk (*e.g.* in terms of population density) (Ferlisi & De Chiara, 2016).

According to Li & Mo (2019) the database "Landslide and Other Mass Movements on Slopes" by the International Association of Engineering Geology (IAEG) indicates approximately 14 % of injuries and deaths in natural catastrophes are caused by slope failures. Studies by the Centre for Research on the Epidemiology of Disasters (CRED) revealed that slope failures caused more than 2.5 million people to become homeless during the first decade of the 21st century. Clague & Roberts (2012) stated that more than 1000 people lose their lives in slope failures worldwide annually.

In Brazil, risk areas associated with slope instabilities are common and the Northeast region of the country fits into this context. According to Santos Junior (2005) the whole coast of the Northeast region of Brazil presents conditions for the development of mass movements. This could be due to the precipitation index of the region and the anthropic action on the physical environment. Landslides are one of the most significant threats to the development of Brazil's Northeast region.

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Over the past 20 years the number of disasters has been increased, due to the increase of the population living in risk areas and the intensification of geodynamic, hydro-meteorological and climate events in the region (Assis Dias et al., 2018).

Information gathered on mass movements in Brazil showed that 38 records of disasters related to landslides were recorded in the period from 1991 to 2012 in the Northeast region of Brazil, which resulted in 55,963,164 people affected (CEPED, 2012). Studies made by Santos et al. (2018) using the Integrated Disaster Information System organized by the Brazilian Ministry of National Integration through the National Secretariat for Civil Defense and Protection (SEDEC) and the University Center for Disaster Studies and Research (CEPED) of the Federal University of Santa Catarina database identified 40 total erosion events and 96 mass movement events for the northeast region between the years of 1980 and 2017 (Table 1). Table 1 also shows the number of cases for all States that comprise the Northeast region of Brazil.

Comprehending the parts of the mass movement process as intimately interconnected could result in significant reduction in the societal and economic losses that the Northeast region of Brazil experiences as a result of slope instability. Thus, the present work aims to survey cases of mass movements that occurred in Northeast region of Brazil that were reported in the academic publications of the Soils and Rocks Journal and the proceedings of three Brazilian academic events, COBRAMSEG (Brazilian Conference on Soil Mechanics and Geotechnical Engineering), COBRAE (Brazilian Conference on Slope Stability) and CBGE (Brazilian Congress on Engineering and Environmental Geology) which constitute the main forum for discussion on the slope stability theme in the Brazilian geotechnical community and determine the factors that contributed to the generation of mass movements on slopes.

Table 1. Erosion and mass movement case records by State of the Northeast region of Brazil from 1980 to 2017.

State	Erosion cases	Mass movement cases
Alagoas	5	0
Bahia	12	25
Ceará	3	1
Maranhão	0	4
Paraíba	3	2
Pernambuco	17	60
Piauí	0	1
Rio Grande do Norte	0	1
Sergipe	0	2

Source: Adapted from Santos et al. (2018).

2. Types and causes of mass movements on slopes

The term mass movement describes a wide variety of processes that result in the downward and outward movement of slope-forming materials. The different types of mass movements can be differentiated by the type of material involved and the mode of movement, making a classification of each type of mass movement necessary in order to better understand the processes that occur during the mass movement. Each classification is associated with the characteristics of the mass and the factors that condition the movements. A classification system based on these parameters was proposed by Varnes (1978) and updated in 2014 by Hungr et al. (2014). This classification system is, to this day, the most widely used (Table 2). According to this system, the types of movements are classified as: Fall, Topple, Slide, Spread, Flow and Slope Deformation. The materials involved in the movements are divided into rocks or soils. The soils movement include boulders, debris, gravel, silt and clay. The words in italics are placeholders, use only one.

Despite not being considered in the Varnes (1978) classification system updated by Hungr et al. (2014), erosions represent a process that develops from a set of dynamic phenomena and processes, which alter the conditions of stability and can lead to risk situations for the population and infrastructure (Gerscovich, 2016). With erosion and mass movements being two forms of land degradation, erosion is considered by many authors as a cause for slope instabilities (Selby, 1993; Nadal-Romero et al., 2014; Gerscovich, 2016; Guerra et al., 2017).

The causes that determine the generation of the mass movements in a slope depend on the phenomenon that contributes to an increase in shear stress on the soil and/or a reduction in shear strength of the soil. According to Giani (1992), the main causes that contribute to a reduction in shear strength depend on soil texture, rock origin and its structural defects. Studies by Suzen & Kaya (2011) recorded 18 different factors used in data-driven landslide hazard or susceptibility assessment procedures in a review of 145 articles between 1986 and 2007. The factors were categorized into four major groups: geological, topographical, geotechnical and environmental. However, according to Budimir et al. (2015), in any given situation, some of these factors may be important whilst others are irrelevant.

The diversity of causative factors influences the different types of mass movement. Within the aforementioned factors, Cruden & Varnes (1996) categorizes the causes or factors that influence mass movements, the main causes of mass movements are divided into the cause groups: geological, morphological, physical and human. The description of these groups is in Table 3.

The origin of landslides might relate to a complex suite of causes and triggers that involve climatic factors, in-

Table 2. Varnes (1978) classification system updated by Hungr et al. (2014).

Type of movement	Rock	Soil
Fall	*Rock / Ice* falls*	*Boulder/debris/silt* fall*
Topple	Rock block topple*	*Gravel/sand/silt* topple*
	Rock flexural topple	-
Slide	Rock rotational slide	*Clay/silt* rotational slide
	Rock planar slide*	*Clay/silt* planar slide
	Rock wedge slide*	*Gravel/sand/debris* slide*
	Rock compound slide	*Clay/silt* compound slide
	Rock irregular slide*	-
Spread	Rock slope spread	*Sand/silt* liquefaction spread*
		Sensitive clay spread*
Flow	Rock/ice avalanche*	*Sand/silt/debris* dry flow
		Sand/silt/debris flowslide*
		Sensitive clay flowslide*
		Debris flow*
		Mud flow*
		Debris flood
		Debris avalanche*
		Earthflow
		Peat flow
Slope deformation	Mountain slope deformation	Soil slope deformation
	Rock slope deformation	Soil creep
		Solifluction

trinsic changes within the rock mass, seismic activity and anthropogenic effects (McColl, 2015). The processes that generate landslides are complex and understanding them depends on the determination of many variables, such as the physical characteristics of the environment, climate, changes in land/soil use, urban growth and vulnerability (Smyth & Royle, 2000).

Table 3. Mass movements groups and descriptions.

Groups	Description
Geologic causes	Weakened materials;
	Sensitive materials;
	Saturated materials;
	Cut material;
	Unstructured or cracked material;
	Adverse oriented discontinuous mass (stratification, schistosity, etc);
	Adverse oriented discontinuous structure (failure, contact, etc.);
	Contrast in permeability;
	Contrast in stiffness (rigid, dense material over plastic material).
Morphological causes	Volcanic or tectonic elevation;
	Glacial expansion;
	Fluvial erosion of the slope;
	Erosion due to crumbling of the slope;
	Underground erosion (cracks, piping);
	Loading on top or bottom of the slope;
	Vegetation removal (fire, drought)
Physical causes	Intense rainfall;
	Rapid melting of snow;
	Extended exceptional precipitation;
	Rapid lowering (by floods and high tides);
	Earthquakes;
	Volcanic eruptions;
	Defrosting;
	Saturation by freezing and thawing;
	Saturation by dilation and contraction.
Human causes	Digging at the top or bottom of the slope;
	Loading on top or bottom of the slope;
	Lowering of reservoirs;
	Deforestation;
	Irrigation;
	Mining;
	Artificial tremor;
	Water leakage from public services.

3. Study area

The Northeast of Brazil is a region comprising 9 States: Maranhão (MA), Piauí (PI), Ceará (CE), Rio Grande do Norte (RN), Paraíba (PB), Pernambuco (PB), Alagoas (AL), Sergipe (SE) and Bahia (BA) (Figure 1). The Northeast Region represents 18 % of Brazilian territory and its area is approximately 1,558,196 km^2. It has a population of 53.6 million people, 28 % of the total population of the country.

Figure 2 presents the simplified geological map of the studied region. The geology can be subdivided into four large units: sedimentary materials from the Cenozoic, the clastic/carbonate sedimentary rocks from the Mesozoic, the clastic and sporadically calcareous rocks from the Paleozoic and the Precambrian Crystalline Rocks.

In the coastal region, sedimentary materials are deposited in marginal basins in the Cenozoic, with emphasis on the Barreiras Formation. The Barreiras Formation consists of a sequence of sediments that covers the entire northeastern coast. They are usually poorly consolidated and formed by layers of silty sand, clayey sand and silty clay (Santos Junior, 2005). The presence of conglomeratic layers is common, as well as lateritic horizons. Dune fields cover the Barreiras Formation in some parts of Rio Grande do Norte, Ceará, Piauí and Maranhão. In the coast of Pernambuco there are outcrops of the Maria Farinha Formation, which is formed by an alternation of clayey limestones and stratified calciferous clays, yellow to gray in color (Gusmão Filho et al., 1982).

The Mesozoic geological units are associated with flat and elevated reliefs due to tectonic processes (Chapadas). According to Costa et al. (2020), this is the case for Chapada do Araripe, which has elevations up to 900 m and steep edges. In some cases, this form of relief occurs associated with the edges of sedimentary basins, such as Chapada do Apodi. Which has levels between 100 and 140 m and cuestiform edges (in the form of a cuesta), adjacent to the Potiguar Basin.

Paleozoic basins in northern Brazil contain thick sequences of sedimentary rocks (Caputo, 1984), more commonly the presence of clastic sedimentary rocks formed by

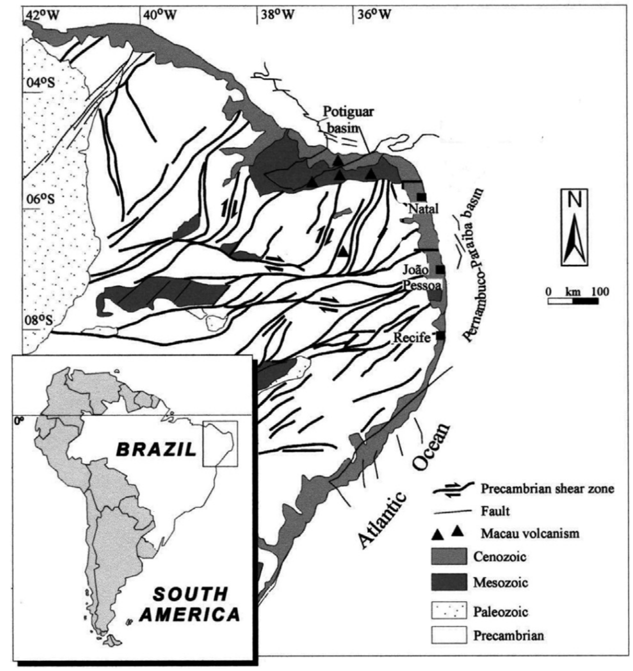

Figure 2. Northeastern geology (Adapted from Bezerra et al., 2001).

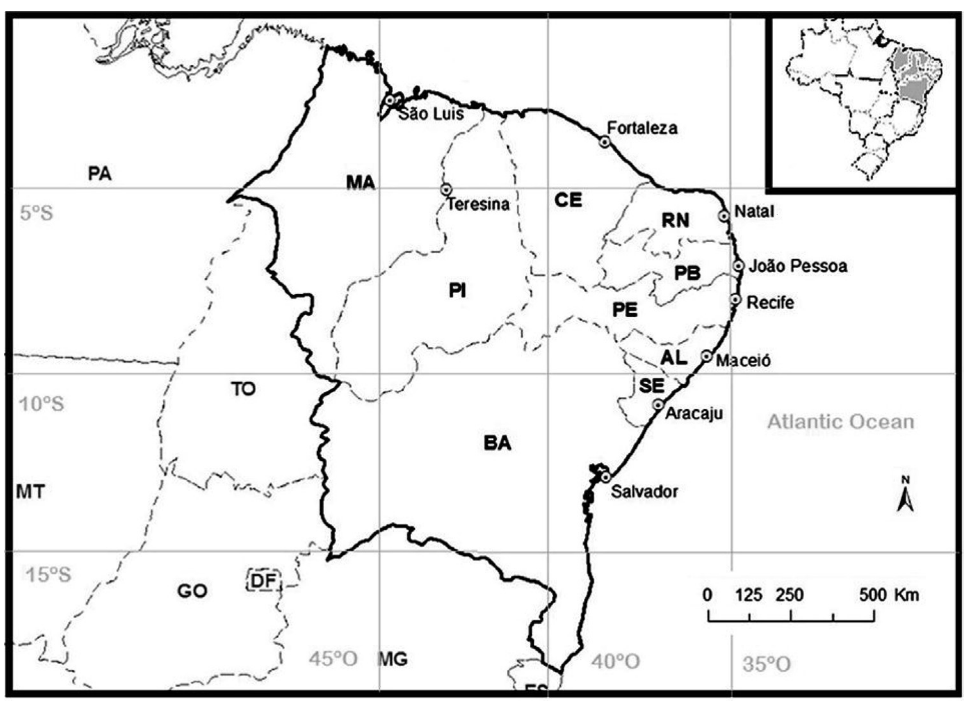

Figure 1. Northeast region of Brazil (Lopo et al., 2014).

the deposition of fragments of magmatic and metamorphic rocks. The Parnaiba basin, whose evolutive processes are chiefly of the Paleozoic age, shows thick cratonic sedimentary sequences that are neatly superimposed on the crystalline basement structures (Almeida et al., 1981).

The Precambrian rocks are of magmatic and metamorphic origin and form the crystalline basement. They emerge in the interior of the studied region. Residual soils are formed by the weathering acting on the crystalline rocks. They are present more expressively in regions where the climate is wet and rainy. This occurs at approximately 100 km from the coast. Deep profiles of residual soil have been reported by Campos (2013) in Salvador and by Coutinho et al. (2019) in Pernambuco.

In geomorphological terms, there is a correspondence between the geology and the relief of the region, which is strongly conditioned by structural aspects. Costa et al. (2020) studied the relief of the septentrional part of the Brazilian Northeast and proposed the existence of the following morphological units associated with the Precambrian rocks located further inland: the Crystalline Massifs (MC), the Sertaneja Surface - SS (subdivided into 1 and 2), the Small Plateaus (PP) and the Pre-coastal Surface (SPL). Figure 3 shows a schematic representation of these relief forms.

The crystalline massifs are the highest areas with altimetric levels ranging from 500 to 900 m. The Sertaneja Surface has levels ranging from 50 to 250 m (Sertaneja Surface 1) and 250 to 400 m (Sertaneja Surface 2). The small Plateaus are flat and elevated reliefs, with levels between 600 and 700 m, which occur in a dispersed manner, mainly in the States of Ceará, Rio Grande do Norte and Paraíba. In some situations, these Plateaus present sedimentary materials and result from the relief inversion by uplift. The Precoastal Surfaces are similar to the Sertaneja Surface with a lower level and constitute the transition with the Coastal Tablelands (Costa et al., 2020).

Closer to the coast are the Coastal Tablelands, supported by the sediments of the Barreiras Formation (Costa et al., 2020). Coastal Tablelands are tabular reliefs formed by sediments that were eroded on the continent, transported and deposited close to the coast. In some sections of Ceará, Rio Grande do Norte, Paraíba and Bahia, the Tablelands extend to the coastline, forming cliffs at the edge of the Tableland. This unity of relief is presented in the form of hills in Paraíba, Pernambuco and Alagoas. According to Costa et al. (2020) these hills result from the dissection caused by the drainage network under more humid conditions. Figure 4 shows a schematic cross section, representative of the conditions in force between the municipalities of João Pessoa in Paraíba and Recife in Pernambuco.

On the coast of the States of Rio Grande do Norte, Ceará, Piauí and Maranhão there are expressive dune fields that result from the accumulation of sandy sediments (fine to medium sands) transported by the action of the wind from the sandy beaches. Also present are the reliefs associated with the Coastal Plains and the Fluvial Plains.

4. Methods

This research aimed to develop a systematic review, using as database the literature available in Brazilian academic sources on the subject of mass movements in the Northeast region of Brazil. This type of review aims to investigate and summarize evidence related to a specific theme by applying detailed search methods, critical analysis and synthesis of the information found.

The first step of the research was the elaboration of the main question for the investigation. Therefore, the purpose of this research was to find the cases of mass movements that occurred in the Northeast region of Brazil that were reported in national academic publications and proceedings.

A manual systematic literature search was conducted following the structure of Figure 5. All papers were searched in the Soils and Rocks Journal and three national

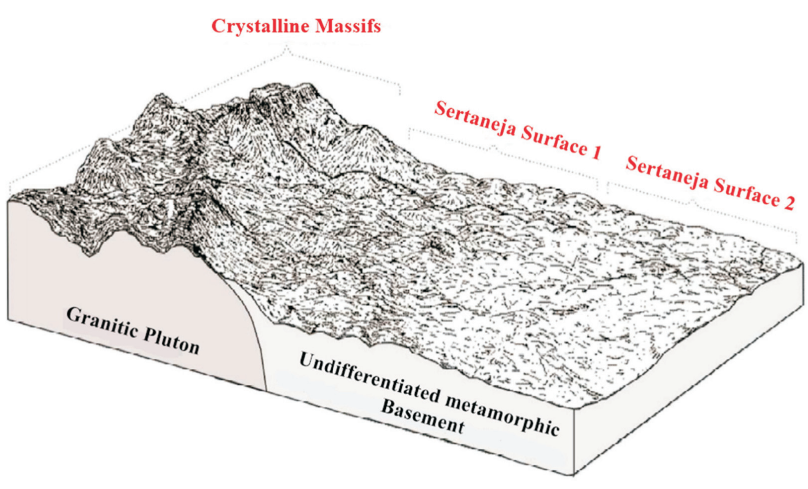

Figure 3. Northeastern geomorphology: Crystalline massifs and Sertaneja surface (Adapted from Costa et al., 2020).

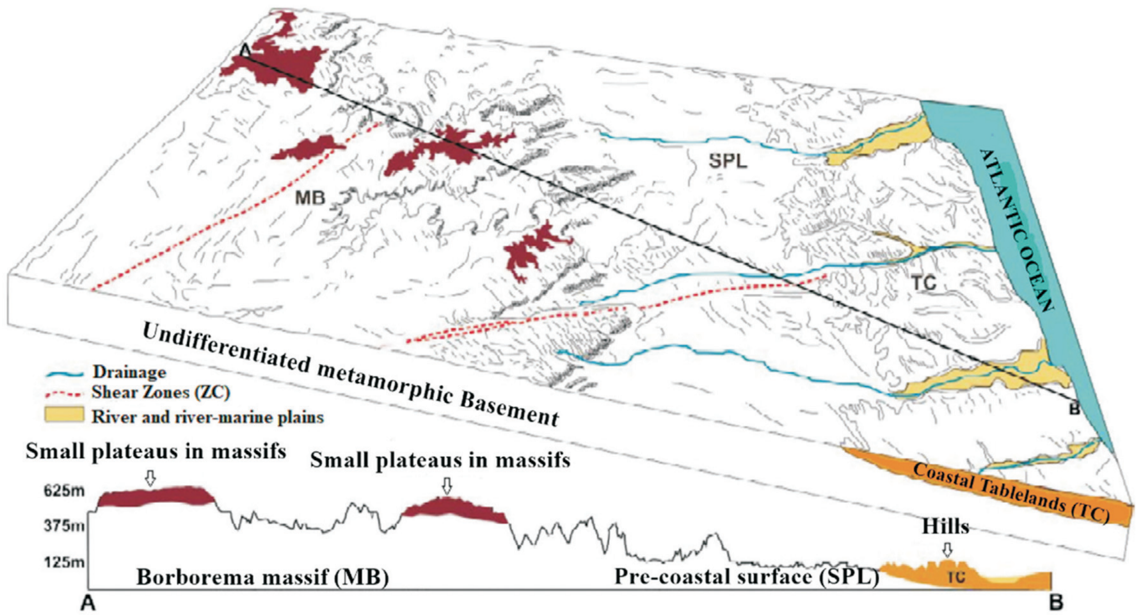

Figure 4. Cross section A-B showing some aspects of Northeastern geomorphology (Adapted from Costa et al., 2020).

academic events, the COBRAMSEG - *Congresso Brasileiro de Mecânica dos Solos e Engenharia Geotécnica* (Brazilian Conference on Soil Mechanics and Geotechnical Engineering), the COBRAE - *Conferência Brasileira sobre Estabilidade de Encostas* (Brazilian Conference on Slope Stability) and CBGE - *Congresso Brasileiro de Geologia de Engenharia e Ambiental* (Brazilian Conference on Engineering and Environmental Geology).

A total of 7348 articles were analyzed. The key words searched were Landslides, Mass Movements, Geomorphology and Engineering Geology restricted to the Brazilian Northeast region within the years of the academic publications and proceedings, between 1954 and 2019. The aim was to determine the number of mass movements that happened in the Brazilian Northeast region and their main causes.

For each step in the systematic search, papers were selected based on a reading of the paper abstract, title and a diagonal reading to determine if the paper was applicable to the study. Of the selected papers, only papers conforming to the aforementioned conditions were accepted into the database. The conformity of the paper to the conditions was determined by a more thorough reading of the papers. Of the 7348 articles searched, 97 articles presented data related to the Brazilian Northeast region. The articles selected were reviewed one by one.

The next criterion for filtering the articles was the presence of the following information within the articles' content: the type of movement, the material involved, the causes, the location and preferably the date of occurrence. Of the 97 articles reviewed, 47 articles were selected based on these criteria. A summary of each article was developed followed by a table with the database obtained for analyses of the data.

5. Results

5.1 Search results by number of events

The studied literature resulted in 47 articles that described mass movement events that occurred in the Northeast region of Brazil. The first and the latest events described in the selected articles occurred in 1944 and 2014, respectively. Of the 47 articles studied, 65 cases of mass movements were accounted. Selected articles are presented in the appendix. The map in Figure 6 shows the occurrence of these mass movements across the States in the Northeast region.

It is observed in the map of Figure 6 that, in general, mass movements present a higher concentration in the State of Pernambuco, showing a higher commitment from the local academic community to study the events that occurred in the State. It was noted from the study of the articles that there is a bigger incentive in the research of mass movements, from the academic point of view, in the States that presented the largest number of mass movement records. Interest in the subject in these States can be attributed to the need for knowledge, since there are a significant number of events occurring in these locations.

According to Santos et al. (2018) the mass movements that occurred in the State of Pernambuco are due to the combination of two factors: physical-natural conditions (geology, relief and climate) and the largest urban concentration in the State associated with disordered occupation. A greater number of occurrences can also be noted in places near the coast, this context is due to the outcropping of the

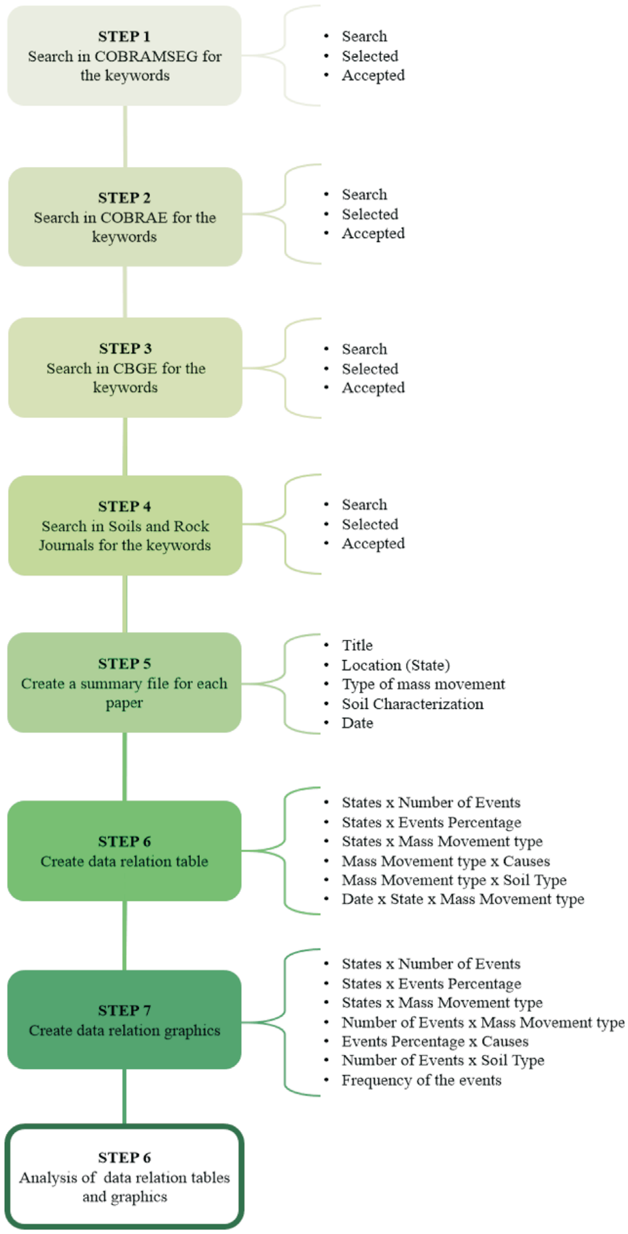

Figure 5. Flowchart for the current research.

crystalline basement that underlines the geological formations of the area in the eastern portion of the country, represented by metamorphic and granitic Precambrian rocks of the Atlantic shield (CEPED, 2012).

The percentages of mass movement records by State that occurred in the Northeast region of Brazil are shown in the graph in Figure 7. The States of Pernambuco and Rio Grande do Norte stand out with the highest number of events, corresponding respectively to 32 % and 31 % of the total mass movements records, followed by the States of Bahia, Alagoas, Ceará and Maranhão with 25 %, 6 %, 5 % and 1 %, respectively. The States of Paraíba, Piauí and Sergipe were the least affected, with 0 % of the mass movements that reached the Northeast within the study period.

According to the data in Table 4, which presents the number of records of mass movements by State, it is verified that the three most affected States were Pernambuco, Rio Grande do Norte and Bahia. The State of Pernambuco presented the largest number of mass movements, with 21 cases described, followed by Rio Grande do Norte and Bahia, which totaled 20 and 16 occurrences, respectively.

Studies conducted by the University Center for Disaster Studies and Research (CEPED, 2012) showed that the States of Pernambuco and Bahia presented the largest percentages of reported mass movements between the years of 1991 and 2012, with 68 % and 21 % respectively, data that agrees with the results obtained by Santos et al. (2018), as shown in Table 1. The University Center for Disaster Studies and Research study also revealed that the States of Rio Grande do Norte and Alagoas did not present reported mass movements between the years of 1991 and 2012, indicating that the events that occurred within these States did not have federal recognition or were not reported by the government.

Torres & Pfaltzgraff (2014) point out that most of the landslides that occur in the urban areas of Pernambuco are the result of the inadequate geometry of the slopes; landfilling without compaction; inadequate vegetation planting; alteration of natural drainages and improper disposal of wastewater.

Through the study it was possible to determine the types of mass movements that occurred in the Brazilian Northeast, the data is presented in Figure 8.

It can be seen from the graph in Figure 8 that the types of mass movements that occur most in the Northeast of Brazil are flow, erosion and slides. With 19 occurrences of flows, 18 occurrences of erosion and 17 occurrences of slides being identified.

The erosion process is defined as the removal of soil particles from the upper parts of the relief by the action of rainwater and wind, resulting in the transport and deposi-

Table 4. Records of the number of mass movement occurrences in the Northeast.

State	Occurrences	Percentage of events (%)
Alagoas	4	6
Bahia	16	25
Ceará	3	5
Maranhão	1	1
Paraíba	0	0
Pernambuco	21	32
Piauí	0	0
Rio Grande do Norte	20	31
Sergipe	0	0

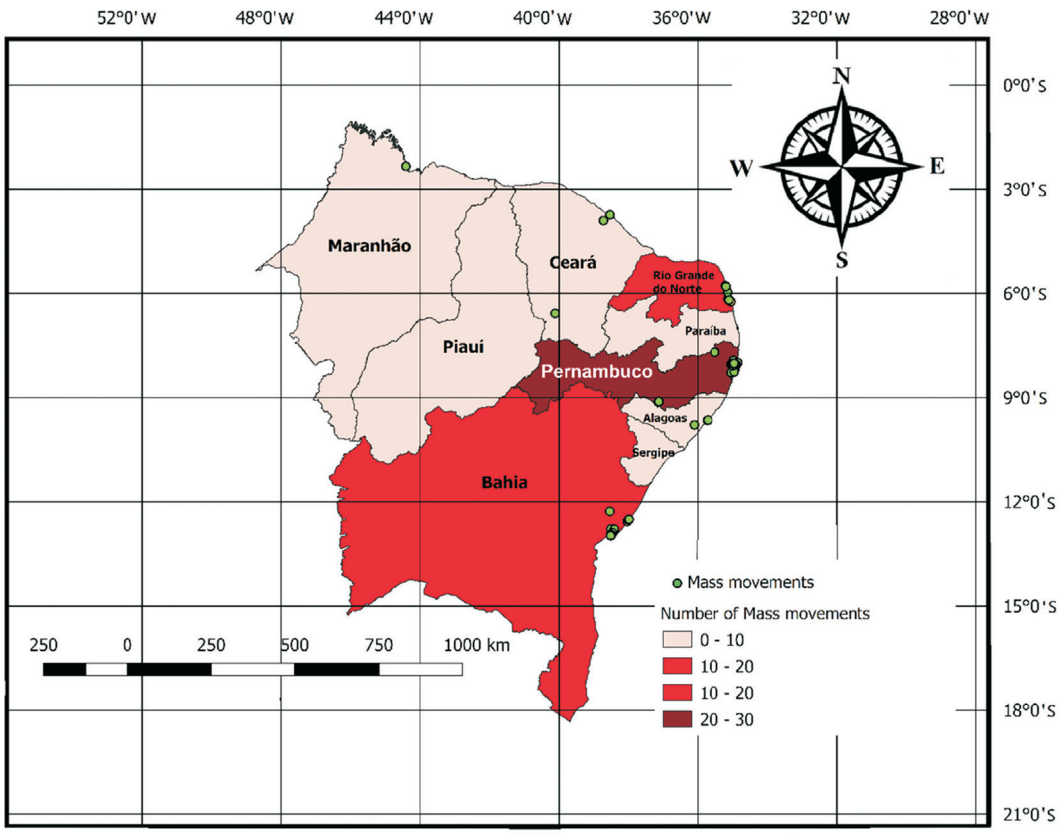

Figure 6. Occurrence of mass movements in the Brazilian Northeastern States.

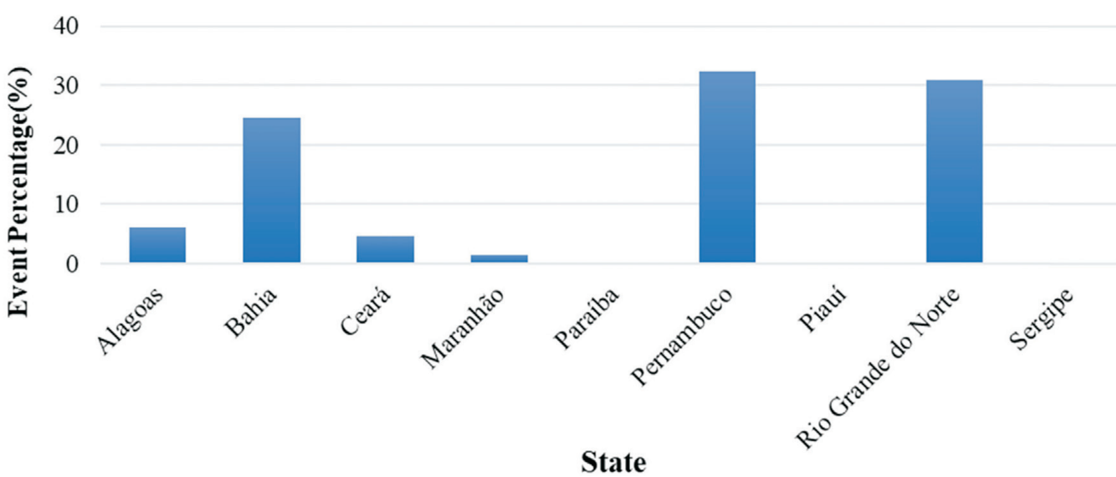

Figure 7. Percentage of mass movements by State.

tion of these particles in the lower portions of the relief or to the bottom of lakes, rivers and oceans (Lepsch, 2002). According to Souza (2014) slides are one of the most important processes related to mass movements in Brazil, due to the geological, geomorphological and climatic characteristics of the country, associated with the intense urbanization and low income power of the population, there is a high frequency of occurrence and a large extension of areas with potential for landslides.

According to Santos et al. (2018), the occurrence of risk areas associated with such phenomena in the Northeast region of Brazil is common, especially in the cities located in coastal regions, where hills and/or tabular reliefs usually predominate with an increase in the urbanization process. Changes in temperature and precipitation have a range of impacts, including the effect in frequency and magnitude of mass movements (Stoffel & Huggel, 2012). The climactic characteristics of the Brazilian Northeast region that are

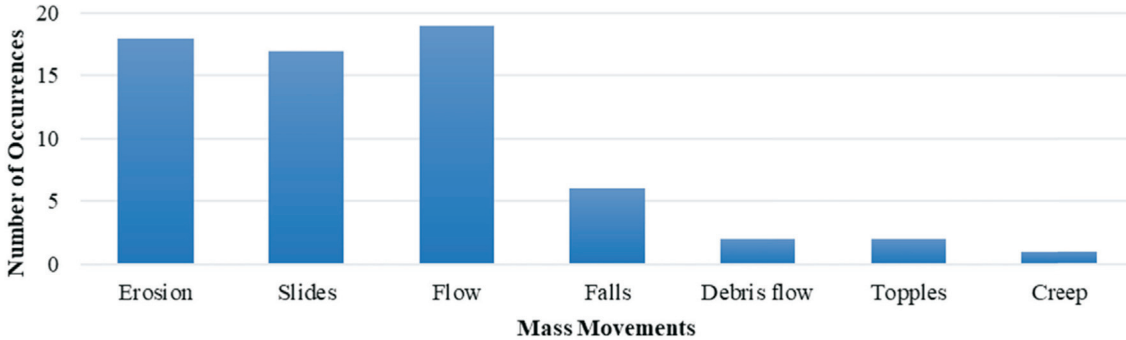

Figure 8. Number of occurrences in the Northeast region of Brazil by mass movement type.

represented by the droughts that periodically affect the location followed by heavy rain seasons, may increase the possibility of mass movements (Handwerger et al., 2019).

Relating the types of mass movements identified by the number of occurrences in each State (Figure 9). It is observed that Pernambuco, Rio Grande do Norte and Bahia are also the States that present the most cases of the three most frequent types of mass movements in the Northeast of Brazil. In addition to the mass movements of higher incidence in the Northeast identified in the graph of Figure 6, Rio Grande do Norte also presents fall and topple events. Of the cases studied in the Brazilian Northeast region, it is clear that these types of movements occur more frequently and in number in cliffs of the Barreiras Formation, which are very present in the State of Rio Grande do Norte. The United States Geological Survey (USGS, 2004) states that falls and topples occur mainly on steep cliffs or slopes, characteristic of the cliffs found on the coast of the State of Rio Grande do Norte.

5.2 Search results by cause

Regarding the causes that culminated in the occurrence of recorded mass movements, five main types of causes in the Northeast region of Brazil were identified. Figure 10 relates these causes to the number of events.

Figure 10 shows that the occurrence of mass movements in the Northeast region of Brazil is associated with a set of factors composed by high precipitation index and anthropic action on the physical environment. The percentage of events that occur due to these causes is much higher than the others. Precipitation and anthropic action are responsible for 41 % and 34 % of the events, respectively. In about 6 % of the occurrences identified in the literature, the determinant causes that led to mass movements were not listed, thus being recorded as not identified in the graph of Figure 10.

The effects of prolonged rainfall on slope stability in soils have been studied by several authors (Sweeney & Robertson, 1979; Chipp et al., 1982; Pitts, 1983; Brand et al., 1984; Tan et al., 1987). Most mass movements occur in places where the soil is in unsaturated conditions and its safety margin against sliding depends on the capillary stresses responsible for the increase of soil strength (Silva, 2006). According to Olivares & Damiano (2007), water infiltration causes a decrease in suction and, consequently, a decrease in soil shear strength that leads to mass movement. The Brazilian Northeast region, being located in the intertropical zone of the Earth, has a high local temperature and badly distributed rainfall throughout the year (Freitas, 2019). This situation, where heavy rain seasons followed

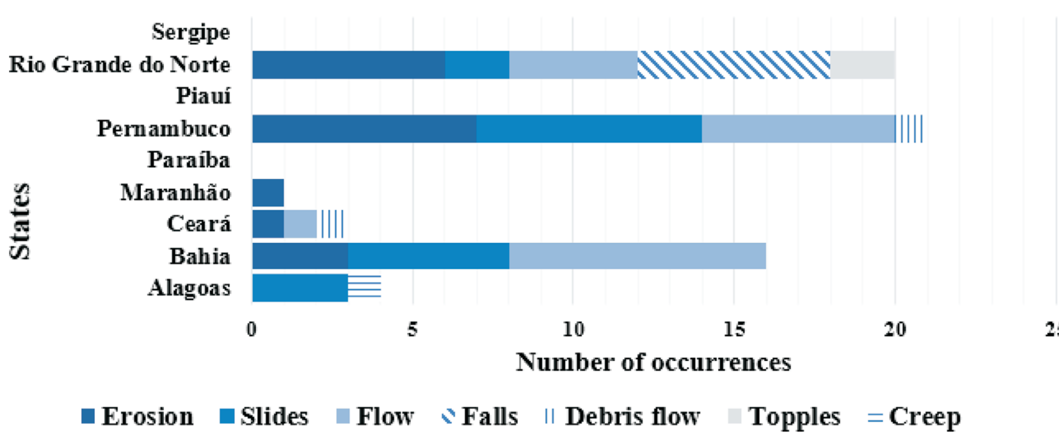

Figure 9. Types of mass movements in the Brazilian Northeast region by State.

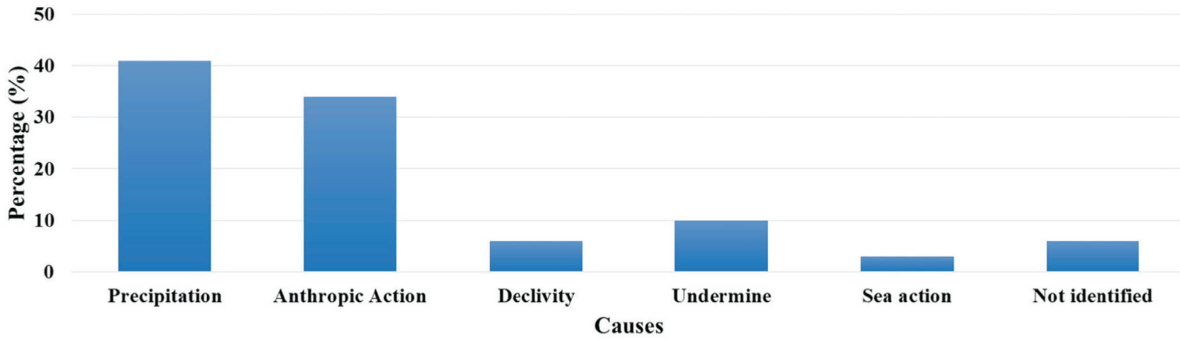

Figure 10. Influence of causes on mass movements in the Brazilian Northeast region.

by severe droughts occur, increases the possibility of natural disaster incidence (Tominaga et al., 2009).

Regarding anthropic actions, it is understood that they are actions derived from human decisions, some examples of these actions would be the civil engineering constructions in inadequate locations, inefficient drainage systems and waste disposal in places with deficiency of stability. It has been observed in the literature that in most of the described cases, the occupations disrespect the capacity of land use, adopting inadequate practices for housing installation, actions that result in mass movements.

5.3 Search results by geological formation

In the Northeast region of Brazil there is an extensive variety of geological formations. From the coast to the interior of the region, the soils are very distinct from each other, both in formation and origin as well as in structure. In the research conducted, the geological formation of each mass movement occurrence was listed in Figure 11, where it relates the geological formation with the number of mass movement occurrences.

It was observed that many of the mass movement events occurred in areas that contained more than one type of material, especially in areas that contained soils from the Barreiras Formation associated with other types of soils from different geological formations, such as Granite and/or gneiss Residual Soils.

Regarding the number of occurrences, the Barreiras Formation soil presented the largest number of events, with 47 occurrences. Most of the Brazilian Northeast is covered by unconsolidated sediments of the Barreiras Formation, whose typical relief form are flat top plateaus (Figure 12). Especially in the metropolitan region of the city of Recife in the State of Pernambuco, the slopes of these plateaus are exposed to landslides during the rainy season (Torres & Pfaltzgraff, 2014). Its thickness varies according to its relationship with the irregular surface of the crystalline basement, on which it rests in erosive disconformity, deepening towards the coast (Brandão, 1995).

The Barreiras Formation has layers of coarse sand, interspersed with layers of fine sand and/or clays, very friable and erodible that favor the installation of erosive processes on the slopes. According to Coutinho & Severo (2009), the clay/sand alternation creates peculiar situations regarding the stability of the slopes in the Barreiras formation. If the slope has clay as its top layer, it will hold the relief, reducing the erosion of the underlying layer; however, if the top

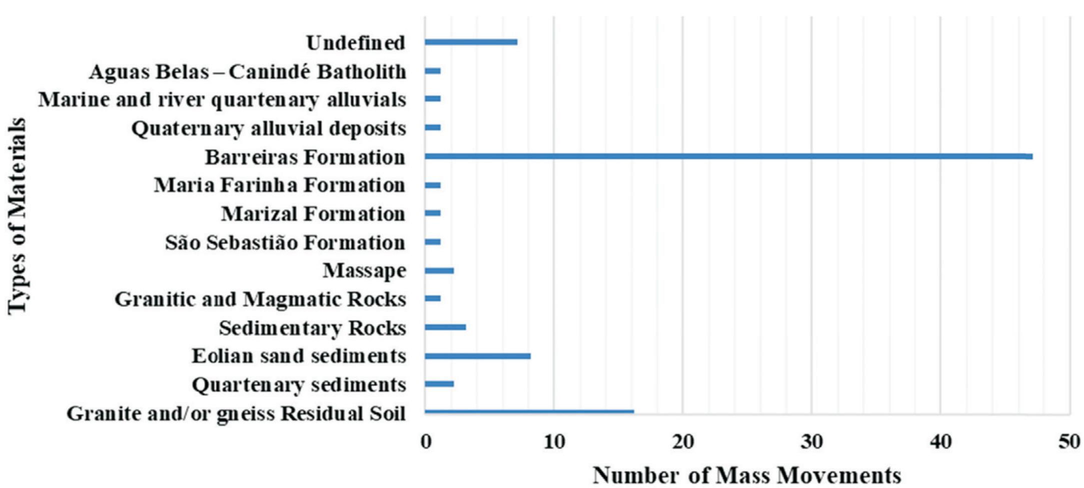

Figure 11. Influence of geological formation on mass movements in Brazilian Northeast region.

Figure 12. Flat top plateaus in Rio Grande do Norte (Muehe, 2006).

layer is sand, high surface infiltration will favor saturation, appearance of erosion processes and possible landslides.

The second material with the largest number of events was residual soils from granite and/or gneiss rocks, with a record of 16 occurrences of mass movements. In general, residual soils present peculiarities in their properties and behavior, due to their performance in geological and/or pedological processes, typical of humid tropical regions. As such, they are most likely unsaturated soils and of relatively high permeability, which means that their engineering properties are easily affected by precipitation (Calle, 2000).

Menezes & Campos (1992) stated that residual soils, in their natural condition present a saturation degree of 80 % or less, when rain occurs, there is an increase in the degree of saturation that causes a reduction in the suction of the soil, consequently there is a decrease in shear strength, which can cause rupture.

5.4 Search results by number of events by year of occurrence

In order to analyze the relevance of the studies on mass movement occurrences in the Northeast region of Brazil, a graph with the number of events by year of occurrence was constructed. The intention of the graph was not to verify how often these events occur, but rather how much, over the years, these events were studied. Figure 13 shows the graph with the number of events that occurred over the years

Figure 13 shows that even though the first article published in this research was from 1954, the first reported event occurred in 1944. The years between 2015 and 2019 did not present recorded events, with the last reported event dated in the articles occurring in 2014. Between the years of 1944 and 1989 there was a record of 10 events, that is, in 45 years only 10 occurrences of mass movement were reported in academic studies. In contrast, from 1991 to 2019 that is, in 23 years, 25 events were recorded in academic events. The higher number of events recorded in recent years can be attributed to the greater need for knowledge on the subject, since there is a significant number of events occurring in the region. The increasing urbanization in the last 20 years brings with it the disordered growth of cities in areas unfit for occupation due to unfavorable geological and geomorphological features. Anthropic interventions in these lands increase the dangers of their instability, requiring solutions to reduce the risk arising from mass movements, solutions that can only be obtained through the study and knowledge of the phenomena that occur on site.

It is also observed from Figure 13 that 30 recorded events have not been dated. The undated events could indicate a lack of precision, accuracy and/or availability regarding the temporal occurrence of the mass movements in the researched articles. The determination of the year in which the events occurred represents an important step towards understanding the causes, frequency and hazards connected to the mass movements. The knowledge about the temporal occurrence of mass movements in a given area may also help to decipher the recent and future responses of slope instabilities to climate change (Pánek, 2015).

6. Conclusions

This research aimed to find the cases of mass movements that occurred in the Northeast region of Brazil that

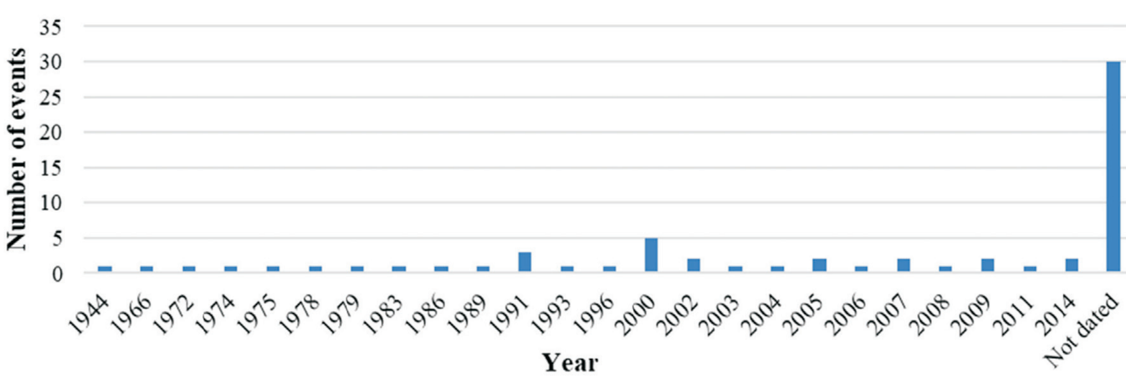

Figure 13. Number of events by year of occurrence.

were reported in national academic publications and proceedings. The data base was comprised of literature available in the Soils and Rocks Journal and three national academic events, the COBRAMSEG (Brazilian Conference on Soil Mechanics and Geotechnical Engineering), the COBRAE (Brazilian Conference on Slope Stability) and CBGE (Brazilian Conference on Engineering and Environmental Geology). The key words searched were Landslides, Mass Movements, Geomorphology and Engineering Geology restricted to the Brazilian Northeast region within the years of the academic publications and proceedings.

With the data and analysis performed, it could be concluded that studies on mass movements in the Northeast of Brazil are still little addressed in academic research. In a period of 65 years of publications, where 7348 articles were analyzed, only 47 of them dealt with research that presented cases of mass movements in the Brazilian Northeast. In several articles studied, the mass movement event was not the object of research but served as a subsidy for the author's study. Out of 65 cases identified, the majority of the events occurred in the States of Pernambuco, Rio Grande do Norte and Bahia. It was also identified that the types of mass movements that occur most frequently in the region are flows, erosion and slides, respectively. The cases of mass movements in the three States with the highest percentage of records were mostly located in the littoral and coastal regions of the States, with depressions such as hills and cliffs.

Regarding the causes of mass movements, precipitation and anthropic actions were presented as the main causes of the events. The effect of rainfall changes the structural organization of the soil, which loses strength, resulting in mass movements. Rainfall in conjunction with anthropic actions, with respect to actions arising from human decisions, were decisive in the occurrence of several of the recorded events. In the analysis of the cases, it was clear that human decisions were a major impact factor in the occurrence of mass movements, especially in those cases reported in settlement sites.

The geological formation that presented the most cases of mass movements was the Barreiras Formation, which is consistent with the locations of occurrence since it is a typical formation of the Brazilian Northeastern coast. The second geological formation with the largest number of cases was the residual soil derived from granite and/or gneiss rocks, also typical of the Northeast region of Brazil. Both geological formations are strongly affected by the actions of rainfall, and with the region being tropical and humid, it can be understood why the events of mass movements occurred in these types of geological formations.

From the research carried out, there was an increase in the number of researches on cases of mass movements in the region. It was noticed that the need for more information and knowledge about the soils, slopes and situation of the locations has become more relevant to the academic community, since it is clear there is a pattern in the disposition of the causes of the events. Several cases have not only involved material losses, but also lives, and the interest in preventing these types of losses also encourages research on the subject.

Systematic reviews are believed to be quite useful for integrating information from various studies with a common theme, in this case, mass movements in the Brazilian Northeast. Therefore, from this systematic review it was possible to identify the main geotechnical characteristics of mass movement occurrences in the region, as well as their causes. It was also identified that this theme is starting to be of more interest to the academic community, as the number of researches involving the theme has been increasing. It is expected that the data presented here will serve as evidence, helping to carry out further research related not only to the subject of mass movements in the Brazilian Northeast, but also to the study of the soils and geological formations and settlements of the region, serving as subsidy for future investigations.

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Appendix - Selected articles

1.	Uma aplicação das micro-ancoragens na estabilização de taludes naturais	VIII Cobramseg	1986	Nunes, A.J.C.; Craizer, W.; Dias, P.H.V.
2.	Mecanismos dos movimentos dos morros de Olinda	VIII Cobramseg	1986	Gusmão Filho, J.A.; Jucá, J.F.T.; Silva, J.M.J.
3.	Ocorrência de voçorocas em plataformas genéticas arenosas em Alcântara - MA	VIII Cobramseg	1986	Vertamatti, E.; Araújo, F.A.R.
4.	A erosão urbana e seus impactos ambientais nos morros da cidade do Recife	IX Cobramseg	1990	Melo, L.V.
5.	Mapeamento de áreas de risco de movimentos de massa em encostas formadas por dunas na cidade de Natal	XI Cobramseg	1998	Santos, L.A.O.; Amaral, R.F.
6.	Análise de estabilidade e proposta de estabilização de uma ruptura ocorrida em encosta com ocupação desordenada no bairro do Ibura, Recife - PB	XIII Cobramseg	2006	Coutinho, R.Q.; Santana, R.G.; Gusmão, A.D.
7.	Análise de soluções de engenharia para contenção em encostas ocupadas na região metropolitana do Recife - PE	XIII Cobramseg	2006	Santana, R.G.; Coutinho, R.Q.
8.	Avaliação da erodibilidade em uma encosta ocupada pertencente à Formação Barreiras	XV Cobramseg	2010	Meira, F.F.D.A.; Coutinho, R.Q.; Cantalice, J.M.B.
9.	Caracterização geológico geotécnica dos materiais presentes nas encostas na região metropolitana do Recife	XV Cobramseg	2010	Bandeira, A.P.N.; Coutinho, R.Q.; Alheiros, M.M.
10.	Chuvas críticas associadas aos escorregamentos de encostas na região metropolitana do Recife	XV Cobramseg	2010	Bandeira, A.P.N.; Coutinho, R.Q.; Alheiros, M.M.
11.	Análise da estabilidade de um movimento de massa ocorrido em Pernambuco	XV Cobramseg	2010	Silva, M.M.; Coutinho, R.Q.; Lacerda, W.A.
12.	Estudos sobre escorregamentos de encostas da formação barreiras de Maceió - AL	XVI Cobramseg	2012	Marques, J.A.F.; Marques, A.G.; Marques, R.F.
13.	Análise da estabilidade de taludes de solos naturais da região metropolitana de Salvador	I COBRAE	1992	Guimarães, R.B.
14.	Condicionamento geológico de uma ruptura de encosta na falha de Salvador	I COBRAE	1992	Santos, L.A.O.; Lima, I.A.; Silva, J.C.B.J.; Leal, G.R.N.
15.	Soil nailing - chumbamento de solos - experiência de uma equipe na aplicação do método	I COBRAE	1992	Zirlis, A.C.; Pitta, C.A.
16.	Tentativa de correlação entre precipitação e deslizamentos na cidade de salvador	I COBRAE	1992	Elbachá, A.T.; Campos, L.E.P.; Bahia, R.F.C.
17.	Escorregamento em morros urbanos do Recife: o caso do boleiro	II COBRAE	1997	Gusmão Filho, J.A.; Ferreira, S.R.M.; Amorim Jr., W.M.
18.	Geotechnical characterization and slope stability evaluation of a slope in residual soil in Pernambuco, Brazil	II COBRAE	1997	Coutinho, R.Q.; Costa, F.Q.; Sousa Neto, J.B.
19.	Situações de risco e medidas de prevenção de acidentes em encostas ocupadas na cidade de Maceió (AL), Brasil	II COBRAE	1997	Anjos, C.A.M.; Cerri, L.E.S.; Gandolfi, N.
20.	Estudo das encostas ocupadas do recife	II COBRAE	1997	Gusmão Filho, J.A.; Alheiros, M.M.; Gusmão, A.D.
21.	Erosão e assoreamento de lagunas no litoral leste do Rio Grande no Norte	III COBRAE	2001	Santos Jr, O.F.; Scudelari, A.C.; Medeiros, A.G.B.; Amaral, R.F.
22.	Inventário e análise das corridas de detritos no Brasil	III COBRAE	2001	Gramani, M.F.; Kanji, M.S.

23.	Mecanismos de ruptura de taludes em sedimentos terciários da Formação Barreiras no Litoral do Rio Grande do Norte	III COBRAE	2001	Santos Jr, O.F.; Pereira, D.A.; Nóbrega, P.G.B.; Amaral, R.F.
24.	Monitoramento de um processo de creep em um talude de massapê	III COBRAE	2001	Machado, S.L.; Presa, E.P.
25.	Análise da estabilidade nas falésias entre Tibau do Sul e Pipa RN	IV COBRAE	2005	Santos Jr, O.F.; Severo, R.N.F.; Freitas Neto, O.; França, F.A.N.
26.	Aplicação de geoprocessamento na avaliação de movimento de massa em Salvador BA	IV COBRAE	2005	Campos, L.E.P.; Miranda, S.B.; Jesus, A.C.; Burgos, P.C.
27.	Avaliação da erodibilidade como parâmetro no estudo de sulcos e ravinas numa encosta no Cabo de Santo Agostinho PE	IV COBRAE	2005	Lafayette, K.P.V.; Coutinho, R.Q.; Queiroz, J.R.S.
28.	Avaliação da susceptibilidade ao risco de uma área piloto de Salvador	IV COBRAE	2005	Jesus, A.C.; Dias, L.S.O.; Miranda, S.B.; Campos, L.E.P.
29.	Avaliação espacial da perda de solo por erosão da bacia experimental de Aiuaba CE através do uso de SIG	IV COBRAE	2005	Cavalcante, S.P.P.; Araújo, J.C.
30.	Caracterização geológica geotécnica de um deslizamento numa encosta em Camaragibe PE	IV COBRAE	2005	Silva, M.M.; Coutinho, R.Q.; Lacerda, W.A.; Alheiros, M.M.
31.	Estabilização de uma área utilizando a contribuição da sucção - o caso de Barro Branco	IV COBRAE	2005	Campos, L.E.P.; Fonseca, E.C.; Burgos, P.C
32.	Quantificação da evolução de erosões em encostas - Cabo de Santo Agostinho PE	IV COBRAE	2005	Silva, E.P.; Coutinho, R.Q.; Lima Filho, M.
33.	Análise e tratamento de erosão na base de uma fundação da linha de transmissão Recife ii-Joairim	V COBRAE	2009	Quental, J.C.; Ferreira, S.R.M.
34.	Avaliação da segurança de um talude não saturado em obra do metrô de Fortaleza CE	V COBRAE	2009	Silva Filho, F.C.; Dantas Neto, S.A.
35.	Avaliação de processos erosivos de falésias em Pirangi do Norte - Parnamirim - RN	V COBRAE	2009	Santos Jr, O.F.; Costa, Y.D.J.; Chaves, L.F.; Costa, C.M.L.
36.	Estudo de um movimento de massa ocorrido numa encosta em Camaragibe PE	V COBRAE	2009	Silva, M.M.; Coutinho R.Q.; Lacerda, W.A.
37.	Proposta para recuperação de uma área degradada no recôncavo baiano	V COBRAE	2009	Araruna Jr., J.T.; Amaral, C.P.; Pires, P.J.M.; Moncada, M.P.H.; Domingues, D.L.P.; Campos, L.E.P.; Burgos, P.C.
38.	Investigação geotécnica para projeto de estabilidade de encostas	V COBRAE	2009	Coutinho, R.Q.; Severo, R.N.F.
39.	Desastres e ações na Bahia	VI COBRAE	2013	Campos, L.E.D.
40.	Escorregamento no maciço do Julião - Salvador	II CBGE	1978	Presa, E.P.; Silva, J.C.F.
41.	Estudo da erosão da encosta do Horto Dois Irmãos - PE	IX CBGE	1999	Coutinho, R.Q.; Oliveira, J.T.R.; Lima Filho, M.F.; Coelho, F.A.B.; Dos Santos, L.M.
42.	Estudo da dinâmica das falésias do município de Tibau do Sul - RN	XI CBGE	2005	De Freitas Neto, O.; Costa, F.A. De A.; Severo, R.N.F.; Santos Jr, O F.; Scudelari, A.C.
43.	Estudo preliminar sobre a adequabilidade das contenções de encostas ao longo da BA 099, litoral norte da Bahia	XIII CBGE	2011	Bastos, E.S.; Lima, C.C.U.; Carneiro, C.S.; Abreu, J.S.
44.	Fatores que ocasionam os movimentos de massa nas encostas entre Guarajuba e Massarandupió, litoral norte do estado da Bahia.	XIII CBGE	2011	Abreu, J.S.; Lima, C.C.U.; Carneiro, C.S.; Bastos, E.S.

45.	Análise de risco remanescente do movimento de massa Ocorrido na comunidade do Jacó - Natal/RN	XV CBGE	2015	Santos, F.G.; Beltrão, B.A.
46.	O desastre na comunidade Mãe Luíza - Natal - RN: fatores de desestabilização relacionados à ocupação antrópica desordenada	XV CBGE	2015	Beltrão, B.A.; Melo, R.C.; Elldorf, B.; Santos, F.G.
47.	Análise das Condicionantes Geológicas da Corrida de Massa ocorrida na Serra das Antas, Águas Belas-PE	XV CBGE	2015	Melo, R.C.; Elldorf, B.; Dias, G.P.