GEOGRAFARES Volume 5, Issue 41
July-December, 2025
e-ISSN: 2175-3709 • https://doi.org/10.47456/geo.v5i41.48785

Conditioning and triggering factors for landslide events in Vitória, Espírito Santo, Brazil

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ABSTRACT

Every year, Brazil experiences landslides that result in widespread damage, several fatalities and disruption in the daily life of the affected population. In this study, we investigated the main types of landslides in Vitória, their conditioning and triggering factors, and spatial distribution. We compiled a landslide inventory from geological-geotechnical reports and tested the independence and correlation of conditioning and triggering causal factors and landslide events. The most common types of landslides in Vitória are shallow slides and rockfalls, clustered around the Central Massif and coastal hills, where talus deposits, residual soils, and rocky outcrops predominate. The main conditioning factors identified were man-made processes (e.g., defects in drainage systems and modifications in slope geometry) and ground conditions (e.g., weathered materials, contrast in permeability), while the main triggering factors are related to rainfall, especially the high prolonged precipitation events.

KEYWORDS: inventory; shallow slides; rainfall.

INTRODUCTION

Landslides are part of the evolutionary process of slopes, present all over the Earth, with thousands of deaths reported annually, most of them in developing countries (Kirschbaum; Stanley; Zhou, 2015), billions of dollars in damages worldwide, and psychological trauma to the humans affected (Amarasinghe *et al.*, 2023). Landslides can be enhanced by human activity, especially the smaller and more frequent events (Sidle; Ochiai, 2006), occurring in isolation or spatial and/or temporal clusters (Guidicini; Nieble, 1983).

Brazil was the country most affected by fatal landslides in Latin America and the Caribbean from 2004 to 2013, and smaller, non-fatal landslides are more common than catastrophic events (Sepúlveda; Petley, 2015). Brazil has registered several disasters related to landslides, especially in the Southeast region (Alcântara *et al.*, 2023; Bonini *et al.*, 2025; Bonini; Vieira; Martins, 2022; Cabral *et al.*, 2023).

Anthropic activities, such as mining, deforestation, excavation and/or loading of slopes are extensively pointed in the literature as one of the main conditioning factors of landslide events (Amarasinghe *et al.*, 2023; Corominas *et al.*, 2014; Froude; Petley, 2018; Popescu, 1994). In Brazil, socially vulnerable areas, such as *favelas*, are often affected by landslides conditioned by man-made processes (Amaral, 1996; Cabral *et al.*, 2023; Ehrlich *et al.*, 2021; Xavier; Listo; Nery, 2022).

The first step to assess the landslide risk of a given area is through an inventory, where is established the frequency of the events, their location, date, types, damages, fatalities, sizes, and conditioning and triggering factors (Corominas *et al.*, 2014; Van Westen; Castellanos; Kuriakose, 2008).

Landslide inventories are classified by the scale or mapping techniques used. Small-scale inventories (<1:200,000) rely mostly on data gathered from the literature, reports, or public services, while medium (1:200,000 to 1:25,000) and large (>1:25,000) scales rely on the use of aerial and/or orbital imagery and field checks. As for the mapping techniques, inventories can be archival (landslide information gathered from the literature or other archive sources) or geomorphological. Geomorphological mapping, in turn, can be classified in historical (the map shows the effects of landsliding over decades, centuries or millennia), seasonal (the map shows landslides over seasons), event (the map shows landslide events triggered by a single cause, e.g., earthquakes, rainfalls, snowmelt), or multitemporal (the map shows landslides triggered by several events over years or decades) (Guzzetti *et al.*, 2012).

Archival and multitemporal landslide inventories using technical reports were made by Amaral (1996) and Salaroli (2003) for the cities of Rio de Janeiro and Vitória, respectively. Zêzere *et al.* (2014) compiled an inventory of landslide and flood events using newspaper articles for Portugal for a 145-year period, while Pereira *et al.* (2014) gathered information from newspapers, technical reports and academic papers for a 110-year period in the North region of Portugal. Further, the authors tested the correlation between rainfall to landslides.

On a global scale, Kirschbaum; Stanley and Zhou (2015), analyzed the amount of landslide reports and fatalities by countries and continents, compared and tested the correlations between landslides and socioeconomic indicators (gross domestic product per capita, population density, distance to roads) and rainfall indexes.

Komac and Hribernik (2015) investigated the Slovenian landslide inventory (archival and multitemporal) and presented information on size (width, length, depth, area and volume), lithological units, types of land use, and if remediation activities were done on past landslides.

Damm and Klose (2015) analyzed a German landslide inventory and presented the regional frequency of landslides, their preparatory and triggering factors, impacts on the population and built infrastructure, and proceeded to model the susceptibility in Lower Saxony. Aristizabal and Sanchez (2020) investigated the spatial distribution of landslides in Colombia, their annual and monthly trends, types, triggers, fatalities and economic losses caused by them, and Li *et al.* (2024) analyzed the occurrence of fatal landslides in China, its annual and monthly distribution, its spatial distribution within provinces and climatic regions, frequency and correlations to rainfall periods.

Carrara and Merenda (1976) produced a historical landslide inventory for northern Calabria (Italy) through field data collection, while Zêzere; Ferreira and Rodrigues (1999) conducted a similar work in the north of Lisbon.

Recently, several event inventories were compiled in Brazil through the use of aerial and/or orbital imagery, such as the Rio Grande do Sul 2024 disaster (Andrades-Filho *et al.*, 2025; Egas *et al.*, 2024) and the São Sebastião 2023 disaster (Bonini *et al.*, 2025; Coelho *et al.*, 2024; Moço *et al.*, 2024), among others (Bonini; Vieira; Martins, 2022; Cardozo *et al.*, 2021; Dias *et al.*, 2023).

In Brazil, other multitemporal landslide inventories were compiled using a combination of several methods, at state (Xavier; Listo; Nery, 2022) and regional scales (Sugiyama *et al.*, 2025).

Regarding how the landslides are represented in a map, though polygons represent best the geometry of a landslide, i.e., crown, body, and deposit (Guzzetti *et al.*, 2012; Reichenbach *et al.*, 2018), and generate more robust results in susceptibility analysis, point data also produces good results in susceptibility analysis (Zêzere *et al.*, 2017).

In Vitória, capital of the state of Espírito Santo, Salaroli (2003), Couto *et al.* (2024), and Pimentel and Bricalli (2023) compiled multitemporal archival landslide inventories for different purposes. Salaroli (2003) compiled reports from the Fire Department, the Municipal Civil Defense and the Mapping of Slope Risk Areas in the Municipality of Vitória project (*Mapeamento das Áreas de Risco das Encostas do Município de Vitória* – Projeto MAPENCO), from 1984 to 2001, and described correlations between landslide events and rainfall. Couto *et al.* (2024) used reports from the MAPENCO project (from 1999 to 2018) to validate a shallow slide susceptibility analysis, and compared the results with morphometric parameters and land zoning, while Pimentel and Bricalli (2023), also using reports from MAPENCO project (from 2006 to 2020), analyzed the spatial relationship between landslides and geological lineaments in Vitória.

The aim of this work is to investigate the landslide events in Vitória, their conditioning and triggering factors, spatial distribution and types, through statistical analysis (associations and correlations) of a multitemporal archival inventory. Vitória has smaller landslides when compared with other Southeastern Brazilian cities, but even small landslide events disrupt the routine of the population, cause damage, and can be fatal and/or destructive. The main types of landslides in Vitória, as identified by Salaroli (2003), are slides and rockfalls, involving soil, rocks and garbage. Future research and risk management practices may benefit from establishing the association between triggering and conditioning factors and landslide events, contributing to more robust land-use planning and disaster risk reduction strategies, though associations (and correlations) do not imply causation.

BACKGROUND

Reporting landslide preparatory and triggering causal factors

The *Working Party on World Landslide Inventory* (WP/WLI) suggested several methods for reporting landslides, their rates of movement, causes, activity, and the distribution of movements within landslides, aiming to establish a standard terminology for describing landslides (Popescu, 1994).

A slope is, at any given time, in one of three stages: stable, marginally stable, and actively unstable. Preparatory causal factors can turn a stable slope into marginally stable, without initiating the slope failure. Triggering causal factors turn a marginally stable slope into actively unstable (Amarasinghe *et al.*, 2023; Popescu, 1994).

Guidicini and Nieble (1983) separate those same factors in predisposing and effective. Predisposing factors are related to natural elements that condition the occurrence of landslides (e.g, geological and morphological settings, climate, gravity, vegetation), and the effective factors are those that trigger the landslide (e.g., rainfall, erosion, snowmelt, earthquake). Elsewhere, those factors are called environmental and triggering factors (Corominas *et al.*, 2014; Van Westen; Castellanos; Kuriakose, 2008), primary and triggering factors (Sidle; Ochiai, 2006), controlling and triggering factors (Egas *et al.*, 2024), conditioning and triggering factors (Pourghasemi *et al.*, 2018), and preparatory and trigger factors (Fell *et al.*, 2008).

According to Popescu (1994), the causal factors can be classified as ground conditions, geomorphological processes, physical processes, and man-made processes. While all groups can be a preparatory causal factor, ground conditions can't be a triggering causal factor.

A succinct list of 40 triggering and preparatory causal factors was proposed by Popescu (1994), classified by their origin, i.e., ground condition, geomorphological processes, physical processes, and man-made processes (Table 1). The reasoning behind the proposed list of causal factors is to simplify the assessment and investigation of landslide occurrences, drawing from preexisting maps and *in situ* observations (for ground conditions, geomorphological and man-made processes) and auxiliary information (such as rainfall gauges, seismographs and piezometers, for the physical processes).

Table 1 – A brief list of landslide causal factors

1. Ground Conditions
1.1 Plastic weak material
1.2 Sensitive material
1.3 Collapsible material
1.4 Weathered material
1.5 Sheared material
1.6 Jointed of fissured material
1.7 Adversely oriented mass discontinuities (including bedding, schistosity, cleavage)

1.8	Adversely oriented mass discontinuities (including faults, unconformities, flexural shears, sedimentary contacts)
1.9	Contrast in permeability and its effects on ground water
1.10	Contrast in stiffness (stiff, dense material over plastic materials)
2. Geomorphological Processes	
2.1	Tectonic uplift
2.2	Volcanic uplift
2.3	Glacial rebound
2.4	Fluvial erosion of the slope toe
2.5	Wave erosion of the slope toe
2.6	Glacial erosion of the slope toe
2.7	Erosion of the lateral margins
2.8	Subterranean erosion (solution, piping)
2.9	Deposition loading the slope crest
2.10	Vegetation removal (by erosion, forest fire, drought)
3. Physical Processes	
3.1	Intense, short period, rainfall
3.2	Rapid melt of deep snow
3.3	Prolonged high precipitation
3.4	Rapid drawdown following floods, high tides or breaching of natural dams
3.5	Earthquake
3.6	Volcanic eruption
3.7	Breaching of crater lakes
3.8	Thawing of permafrost
3.9	Freeze and thaw weathering
3.10	Shrink and swell weathering of expansive soils
4. Man-made Processes	
4.1	Excavation of the slope or at its toe
4.2	Loading of the slope or at its crest
4.3	Drawdown (of reservoirs)
4.4	Irrigation
4.5	Defective maintenance of drainage system
4.6	Water leakage from services (water supplies sewers, stormwater drains)
4.7	Vegetation removal (deforestation)
4.8	Mining and quarrying (open pits or underground galleries)
4.9	Creation of dumps of very loose waste
4.10	Artificial vibration (including traffic, pile driving, heavy machinery)

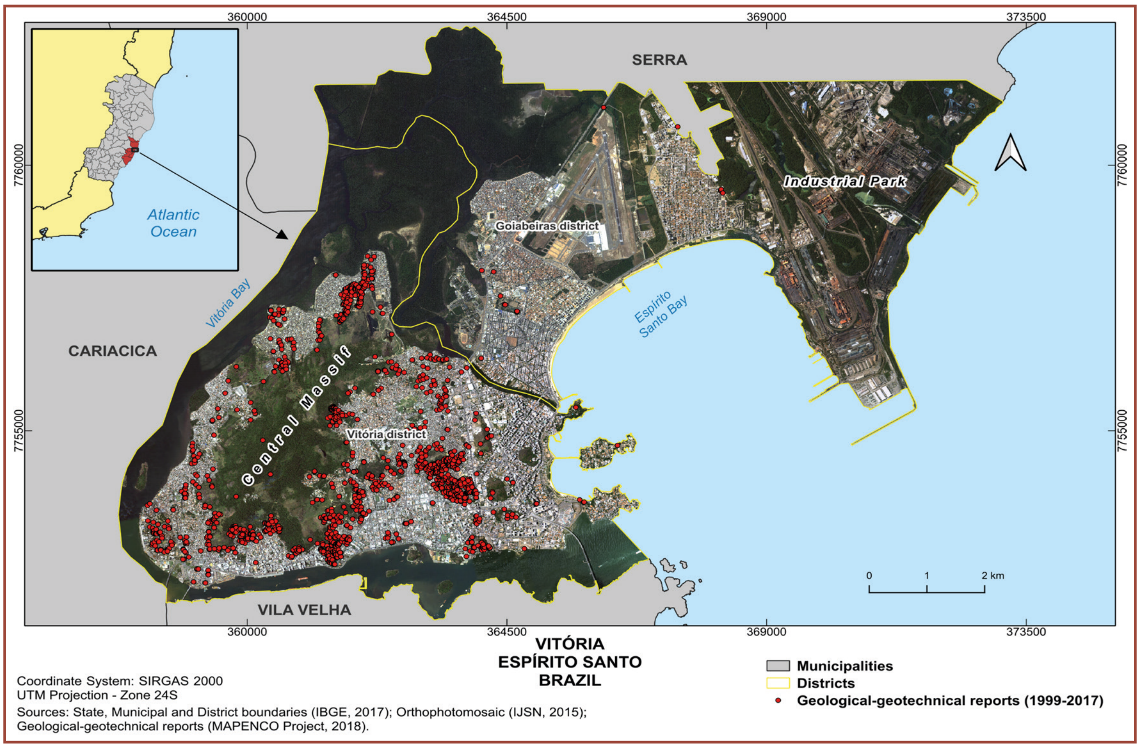
Source: Popescu (1994).

STUDY AREA

Vitória is the capital of Espírito Santo, located in Southeastern Brazil, bordering the states of Bahia, Minas Gerais, and Rio de Janeiro. Vitória has roughly 322,000 inhabitants, close to 8.4% of the state population. The Greater Vitória Metropolitan Region, made up of Vitória and six other municipalities, houses about half of the state's population (IBGE, 2024).

Vitória's territory covers 97 km² and is divided into two districts on the mainland, Goiabeiras and Vitória (Figure 1), and two oceanic islands about 1,100 km from the mainland. Protected areas (excluding the islands) are 43% of the area of the municipality and concentrate on the Central Massif and the mangrove at the north of Vitória (PMV, 2023). The Goiabeiras district composes the continental part of the municipality, while the Vitória district is an island surrounded by two bays: Vitória bay, to the west, and Espírito Santo bay, to the east (Machado *et al.*, 2018).

Figure 1 – Map of Vitória, with geological-geotechnical reports registered between 1999 and 2017



Source: IBGE (2017); IJSN (2015); and MAPENCO Project (2018). Organized by the authors.

The climate in Vitória is classified as *Am* (tropical with a monsoon season), with an average annual temperature of 25.5° C and a mean annual rainfall of 1,355.4 ± 348.8 mm, with the wettest period from November to January (Effgen *et al.*, 2020). The main influences on Vitória's climate are the cold fronts, the South Atlantic Convergence Zones, and the South Atlantic Subtropical Cyclones (Marchioro, 2012; Marchioro; Silva; Correa, 2016; Roza *et al.*, 2023).

The municipality's geology follows the division of the districts. In the Vitória district, the Central Massif, the coastal hills and the islands are made up of Cambrian fine-to-medium grained alkaline granites and gneisses, while the low-lying areas are made up of fluvio-marine deposits. The Goiabeiras district is composed of Tertiary tablelands, part of the Barreiras Formation, which are formed by poorly selected detrital deposits, with laterite horizons, and gravelly, sandy, and clayey sediments, to the northeast, and fluvio-marine deposits (Machado *et al.*, 2018; SGB, 2014).

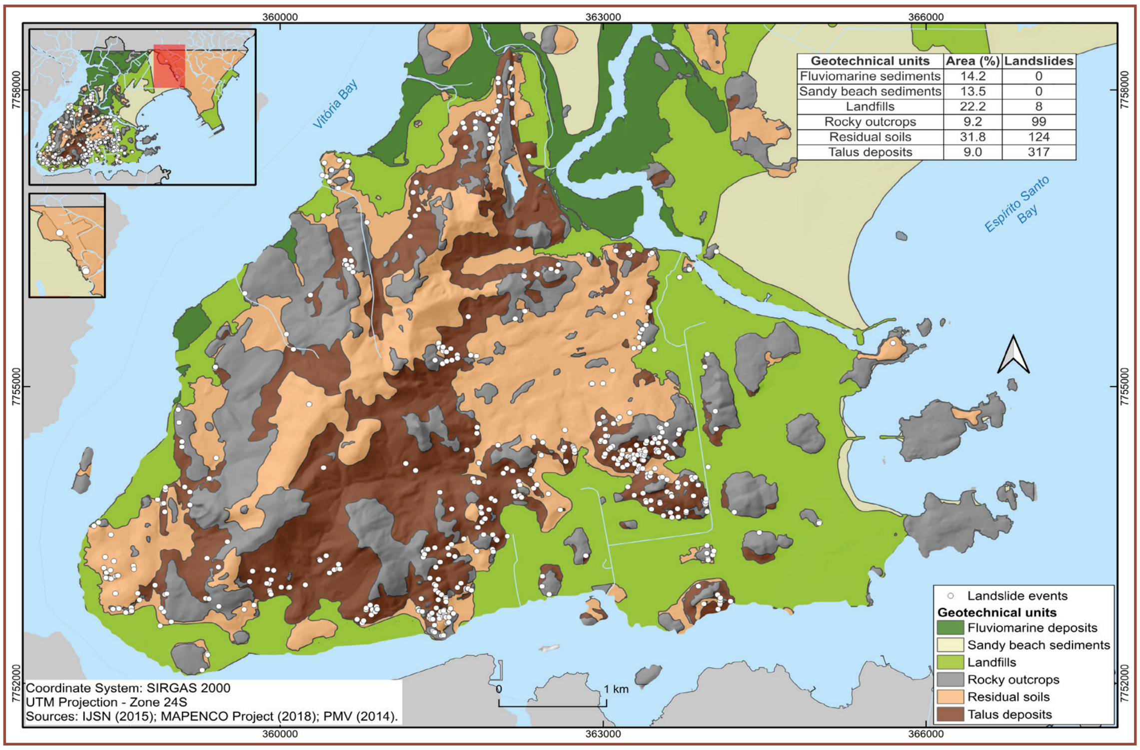
Most of the geotechnical reports were registered on the Vitória district, along the Central Massif and coastal hills, while very few of them were registered at the Goiabeiras district, in the tablelands and isolated coastal hills (Figure 1). The Central Massif of Vitória has a high density of lineaments and geological structures and landslides (Pimentel; Bricalli, 2023; Salaroli, 2003). Structural features can form pathways to water infiltration into the soil and bedrock, creating planes of different permeabilities (on soil-soil, soil-rock, or rock-rock contacts), favoring landslides (Sidle; Ochiai, 2006). Effgen *et al.* (2020) and Couto *et al.* (2024) identified, through soil textural analysis, permeability contrasts in the soils of a watershed in the Central Massif in Vitória that could lead to landslides events, though most landslides are linked to human activities.

There are six geotechnical units in the municipality (Figure 2), and the ones located in flat areas correspond to half of the area of Vitória (i.e., fluvial-marine deposits, sandy beach sediments, and landfills) are the least prone to landslides processes, although they are subject to flooding and lateral bank erosion (PMV, 2014).

Talus deposits are 9% of the total area of geotechnical units but have 965 geotechnical reports registered (Figure 2). This unit is associated with the steep slopes of the Central Massif and coastal hills. The bearing capacity varies from medium to low, with heterogeneous texture, high porosity, and medium to high permeability, making this geotechnical unit prone to erosive processes and landslides, especially soil slides and rockfalls (PMV, 2014). Bortoloti *et al.* (2015) pointed that landslides in Vitória are related to cuts in slopes made of talus deposits and destabilization of rock masses.

Residual soils are the largest geotechnical unit in Vitória (31.8%), distributed across both districts. In the Goiabeiras district, the residual soils are in the Barreiras Formation and close to rocky outcrops, while on the Vitória district the residual soils are adjacent to rocky outcrops and talus deposits. This unit has 298 geotechnical reports reported. The susceptibility to erosion is intermediate, while the susceptibility to shallow slides is associated with vertical cuts on the slopes (PMV, 2014).

Figure 2 – Geological-geotechnical reports in geotechnical units in Vitória



Source: IJSN (2015); MAPENCO Project (2018); PMV (2014). Organized by the authors.

Rocky outcrops represent 9.2% of the geotechnical units in Vitória, and are associated to the coastal hills, islands and around the Central Massif. This unit occasionally has thin layers of soil, with good stability for cuts, but moderate when boulders and blocks are present. This unit is therefore prone to rockfalls (PMV, 2014).

DATA AND METHODS

The landslide inventory was compiled from geological-geotechnical reports made available by the Municipal Department of Construction and Housing of Vitória (*Secretaria Municipal de Obras* – SEMOB) in PDF files and a shapefile with point data, which represent the sites surveyed by the MAPENCO project team.

The geological-geotechnical reports were made by the MAPENCO project (2018) and describe surveys of landslide events and inspections conducted by the project team. Every report has a brief geological and geotechnical description of the site, pictures, a full description of the inspection or event, and a conclusion with a course of action to be taken by the Civil Defense and/or Mayorship (blocking of roads, residences, demolitions, removal of residents from high-risk areas, etc.). Inspection reports describe visits made by the MAPENCO project team to locations where structural interventions for slope containment were taking place or where a resident called for inspection and risk assessment, with no immediate landslide event associated. Landslide event reports describe the events, the triggering factors, where and when the landslide happened and the conditioning factors.

The reports analyzed ranged from January 1999 to April 2018, totaling 1,653 PDF files, and the statistical analyses were conducted only in complete years (i.e., 1999-2017) using Excel spreadsheets. The geological-geotechnical reports were obtained in April 2018, during the first author's Doctorate. Information such as identification code, year, neighborhoods, coordinates, type of report (inspection or event), event date, report date, and type of landslide was tabulated on a spreadsheet. Several reports did not contain any or had as little as information on the exact time or date of events, allowing for limited temporal analysis. Some reports had precise dates of events, but the majority had no or vague information (e.g., "the second quarter of November", "last rainy period", "last summer" or "in the past few days"). When the date of the landslide events was absent, the report date was used as proxy. As for the time of events, most of the reports have no information at all, while some of the reports have vague information (e.g., "afternoon", "past midnight", "morning") and very few had precise information.

The triggering and preparatory causal factors were compiled from the reports, through textual descriptions and pictures, organized according to Popescu (1994), and counted for statistical analysis.

Rainfall data was used to calculate the mean monthly, seasonal and annual rainfall. Climate data was extracted from the "Vitória-ES" station (code ES-83648) from the National Institute of Meteorology (INMET, 2019), for the period of 1993 to 2019.

Due to the aforementioned lack of information on the precise time and date of landslide events, the relationship between landslide events and rainfall extremes was not analyzed.

Geoprocessing and statistical analyses

The intersection between the geological-geotechnical reports and the geotechnical units (PMV, 2014) were extracted using the Point Sampling Tool

QGIS plugin, available in QGIS 3.42 (2025). All maps were projected in the Universal Transverse Mercator (UTM), Zone 24S, using the SIRGAS 2000 Coordinate System.

Pearson's Chi-square (X^2) test and Phi coefficient (φ) were used to verify the association between landslide events and preparatory and triggering causal events, following Komac and Hribernik (2015).

The chi-square tests the independence between categorical variables (in this work, landslide events and triggering or preparatory causal events), where the null hypothesis (H_0) represents independence between variables, while the alternative hypothesis (H_1) represents association between variables. When the calculated value of X^2 is bigger than the critical value of X^2 (according to the reference distribution), the null hypothesis is rejected in favor of the alternative hypothesis. Also, the larger the X^2, the stronger the association is (Ott; Longnecker, 2016). The Phi coefficient measures the strength of the association, in an interval from 0 to 1 (i.e., none to perfect association) (Blaikie, 2003).

Spearman's rank (r_s) correlations analysis was used to test the association between reports and mean monthly, seasonal and annual rainfall, following several authors (Cabral *et al.*, 2023; Damm; Klose, 2015; Froude; Petley, 2018; Kirschbaum; Stanley; Zhou, 2015; Li *et al.*, 2024; Pereira *et al.*, 2014; Sepúlveda; Petley, 2015). The Spearman's rank correlation test is rank-based, allowing test association between ordinal variables (Blaikie, 2003; Ott; Longnecker, 2016).

The null hypothesis (H_0) for the correlation tests in this work is that there is no association between reports and rainfall; the alternative hypothesis (H_1) is that there is association between reports and rainfall.

Results for all tests were considered significant with a *p-value* of 0.05 or less (i.e., the data fails to support H_0; conversely, if the p-value > 0.05, the data fails to reject H_0, thus accepting the H_1). It is crucial to highlight that associations do not mean causalities (Ott; Longnecker, 2016). The tests were performed in SPSS 26 (IBM, 2019).

LANDSLIDES IN VITÓRIA

Vitória had 1,609 geological-geotechnical reports registered from 1999 to 2017. Averaging 84 reports per year, 548 were event reports and 1,061 were inspection reports (Table 2). The years with the most reports registered were 2001, 2009, 2013, 2014, 2015, and 2017, with over a hundred reports per year. On the other hand, the years with the least records were 2006, 2007, 2008, and 2010.

Table 2 – Types of geological-geotechnical reports and annual rainfall in Vitória

Year	Event reports	Inspection reports	Total reports	Annual rainfall (mm)
1999	48	35	83	1,401.9
2000	26	62	88	1,562.2
2001	31	75	106	1,362.8
2002	18	52	70	1,030.5
2003	21	43	64	989.1
2004	44	50	94	1,649.9
2005	26	43	69	1,790.5
2006	2	17	19	1,384.6
2007	7	6	13	878
2008	17	37	54	1,524.3
2009	38	85	123	1,570.7
2010	12	37	49	1,224.1
2011	29	38	67	1,591.2
2012	40	43	83	1,599.1
2013	75	70	145	2,194.6
2014	64	76	140	990.6
2015	15	105	120	728
2016	8	83	91	948.4
2017	27	104	131	1,262.8
TOTAL	548 (34%)	1,061 (66%)	1,609 (100%)	

Source: INMET (2019); MAPENCO Project (2018). Organized by the authors.

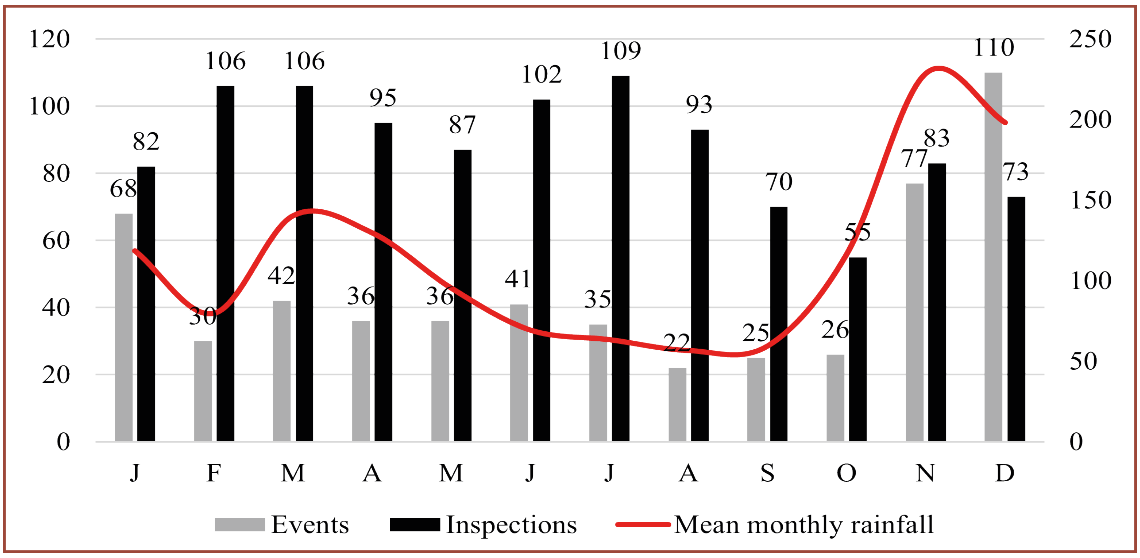
The number of reports tends to follow the annual rainfall, with an increase in event reports in wetter years and an increase in inspection reports in drier years. Other explanations for the fluctuation in the number of reports registered over the years include investments in structural works of prevention and containment, in the organization of secretariats linked to Civil Defense (Amaral, 1996), and the population's fear of new events (Salaroli, 2003).

The years following major climatic events that led to landslides (or floods) have an increase in total reports due to requests for inspections. As an example, in December 2013, a South Atlantic Convergence Zone (SACZ) caused an extreme rainfall event in Espírito Santo and eastern Minas Gerais, with a positive anomaly of 570.6 mm in Vitória (Silva *et al.*, 2014). Therefore, the years 2014, 2015, 2016, and 2017 (all with annual rainfall below the annual average) have more inspections than recorded events.

The relationship between annual rainfall and event reports is positive and moderate (r_s=0.575, *p*=0.01), while there is no significant relationship between inspections and annual rainfall. Similar relationship was found in Germany, though the correlation between landslides and annual rainfall was moderate and positive (Damm; Klose, 2015).

The relationship between the geological-geotechnical reports and the average monthly rainfall in Vitória (Figure 3) shows a very strong, positive correlation between landslide events and the average monthly rainfall (r_s=0.814, *p*=0.001), while there is no significant relationship between inspections and average monthly rainfall. Average monthly rainfall was found to be strongly correlated to landslides in China (Li *et al.*, 2024), and very strongly correlated in Central and South America and South and East Asia (Froude; Petley, 2018).

Figure 3 – Comparison of geological-geotechnical reports and average monthly rainfall in Vitória



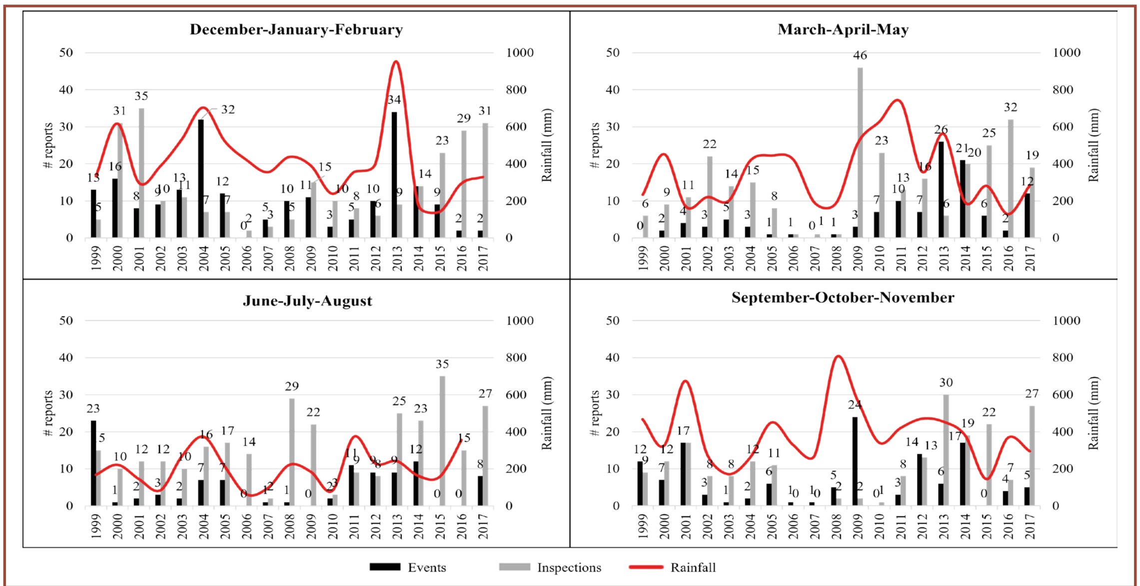
Source: INMET (2019); MAPENCO Project (2018). Organized by the authors.

Therefore, rainfall (either annual or average monthly) is not related to inspection reports, but the average monthly rainfall is a stronger predictor of landslide events than annual rainfall. Event reports follow the average monthly rainfall, increasing during the wetter season, and decreasing over the drier season in Vitória. During the winter, the number of inspections increases due to the lack of simultaneous emergencies, in contrast to the wetter season.

Analyzing reports ranging between 1984-2001, and using the MAPENCO Project, Municipal Civil Defense and the Fire Department as sources, Salaroli (2003) found a similar relationship between the number of reports registered and annual and monthly rainfall for Vitória.

Inspection reports and rainfall in any season are not related, as well as event reports and rainfall during the fall (March-April-May) – Figure 4. The strongest relationship is between the spring rainfall (September, October, November) and event reports (r_s=0.773, p<0.001), followed by summer (December-January-February; r_s=0.548, p=0.015), and winter (June-July-August; r_s=0.482, p=0.036). The landslide events follow both the decrease of rainfall during winter and the increase of rainfall in the spring and summer, though other factors may influence the occurrence of landslides over the years (e.g., drier/wetter year cycles, torrential events, structural remedial measures, etc.).

Figure 4 – Comparison of geological-geotechnical reports and seasonal rainfall in Vitória

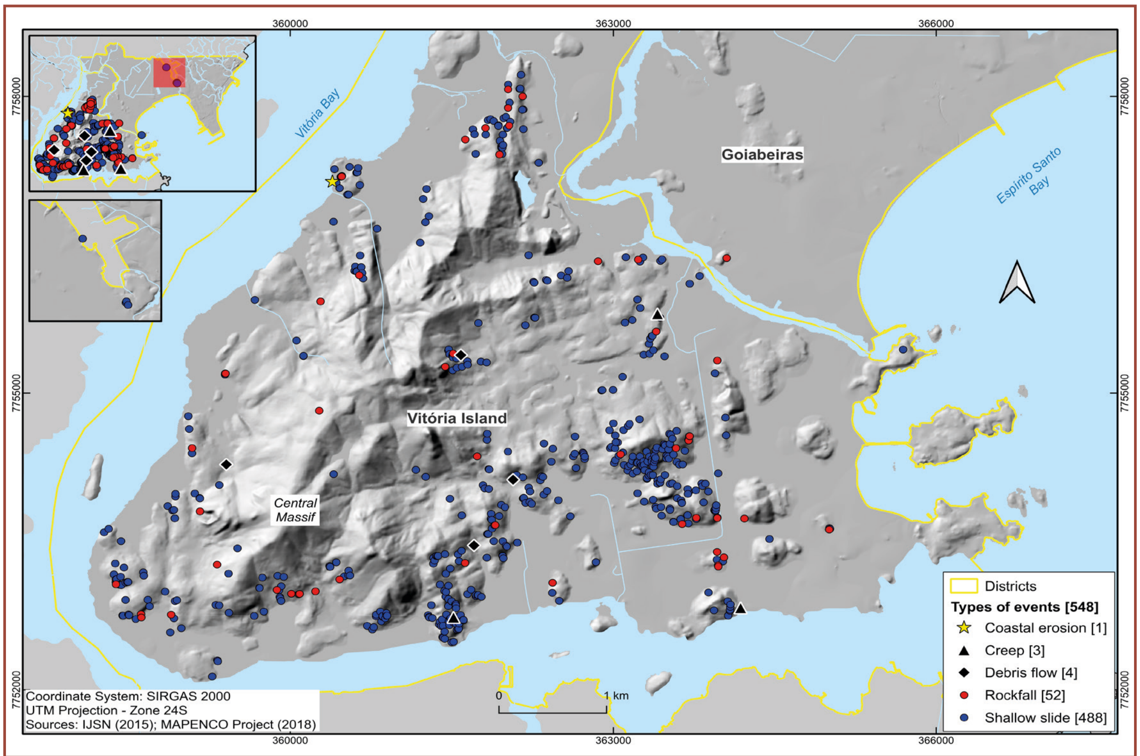


Source: INMET (2019); MAPENCO Project (2018). Organized by the authors.

The relationship between rainfall and landslides is often investigated due to its role as a triggering factor, especially in the tropical region (Amarasinghe *et al.*, 2023). Cabral *et al.* (2023) found that the relationship between the magnitude of debris flows and hourly rainfall in Brazil is strong and positive, and Sepúlveda and Petley (2015) found a strong correlation between mean annual rainfall and fatal landslides in Latin America.

As for typologies, shallow slides are the most common type of landslide registered in Vitória (Figure 5), with 488 event reports – 89.1% of all reports from 1999 to 2017. Most of the shallow slides concentrated in the Vitória district, on the slopes of the Central Massif and coastal hills, where talus deposits, rocky outcrops and residual soils are abundant. Rockfalls were the subject of 52 event reports (9.5%), associated with rocky outcrops and boulders exhumed from the soil matrix. Debris flows, creeps, and coastal erosion were the subject of only four, three, and one event reports, respectively. The district of Goiabeiras was the least affected by landslides, with only five events registered, with four shallow slides along the contact between the Barreiras tablelands and the fluvial-marine and marine plains, and one rockfall on a rocky outcrop.

Figure 5 – Distribution of landslides events recorded in Vitória (1999-2017)



Source: IJSN (2015); MAPENCO Project (2018). Organized by the authors.

Our findings are similar to those of Salaroli (2003), who found that most landslides happened associated to the cutting of slopes to house construction in Vitória district, in the talus deposits, colluvial soil, and rocky outcrops geotechnical units. Moreover, the prevalence of shallow slides in Vitória follows its prevalence noted elsewhere, mostly due to the thin layers of soil over weathered bedrock in hillsides being modified by human activities, like Rio de Janeiro (Amaral, 1996; Ehrlich *et al.*, 2021) and Petrópolis (Alcântara *et al.*, 2023), both at the Rio de Janeiro state, and the Colombian Andes (Aristizabal; Sanchez, 2020).

Preparatory causal factors

In Vitória, 15 preparatory causal factors were described in the landslide event reports, with no physical process factors among them and only one geomorphological process (Table 3). Eight of the preparatory causal factors are related to man-made processes (group 4), with 96.9% of all landslide event reports describing some form of defective maintenance of the drainage system, which saturates and contributes to slope failure. Changes in slope geometry, such as slope excavation and/or loading, are related to the construction of houses and roads in Vitória and were described in 81.9% and 69.9% of the landslide event reports, respectively.

Table 3 – Preparatory causal factors described in landslide event reports, ordered by relevance

Preparatory causal factors[a]		n	%[b]
4.5	Defective maintenance of the drainage system	531	96.9%
1.4	Weathered material	450	82.1%
4.1	Excavation of the slope or at its toe	449	81.9%
4.2	Loading of the slope or at its crest	383	69.9%
1.9	Contrast in permeability and its effects on groundwater	332	60.6%
4.9	Creation of dumps of very loose waste	183	33.4%
1.6	Jointed or fissured material	135	24.6%
4.6	Water leakage from services (water supplies sewers, stormwater drains)	41	7.5%
4.7	Vegetation removal (deforestation)	18	3.3%
4.8	Mining and quarrying (open pits or underground galleries)	7	1.3%
4.10	Artificial vibration (including traffic, pile driving, heavy machinery)	3	0.5%
1.8	Adversely oriented mass discontinuities (including faults, unconformities, flexural shears, and sedimentary contacts)	2	0.4%
2.5	Wave erosion of the slope toe	1	0.2%
1.5	Sheared material	1	0.2%
1.1	Plastic weak material	1	0.2%

[a] The first digit corresponds to the group of factors as follows: 1) ground conditions; 2) geomorphological processes; and 4) man-made processes.

[b] The frequency is calculated based on the 548 event reports during the 1999-2017 period.

Source: organized by the authors.

The prevalence of man-made processes over the other groups of preparatory causal factors stems from the origins of the reports (i.e., inspections conducted by the Municipal Department of Construction and Housing of Vitória) and the way the territory was occupied. The inspections and follow-up reports were made, usually, after calls from the population, hence the slopes analyzed were anthropized. Further, urban use corresponds to almost half the area of the municipality (IBGE, 2023) and sprawl is constrained by the jagged relief and protected areas. Of the 548 event reports, twelve have no man-made preparatory causal factor described (7 rockfalls and 5 shallow slides).

Six of the preparatory causal factors described in landslide event reports in Vitória are from group 1 (ground conditions, as in *Table 1*). The most prevalent are related to weathered materials (82.1%), permeability contrast and its effects on groundwater (60.6%), and jointed or fissured materials (24.6%). Weathering of slope materials can create soils less resistant to shearing stress (with lower cohesion and angle of internal friction than the parent material) and with different hydromechanical behavior between layers, which contributes to slope failure (Sidle; Ochiai, 2006).

Landslide events and the ground conditions and man-made processes groups are associated, i.e., the presence of certain aspects of ground conditions and/or human activities turns a slope prone to landslide. The associations were weak, showing that the presence of a preparatory causal factor is not determinant for landslide occurrence, although the association with man-made processes is slightly stronger than the association with ground conditions (ground conditions: X^2=9.941, φ=0.135; and man-made processes: X^2=34.119, φ=0.250; with p-values < 0.005). Geomorphological processes were not tested due to the low number of cases. Our findings on the importance of man-made processes over other preparatory causal factors in Vitória agree with others (Couto *et al.*, 2024; Salaroli, 2003), though the landslide data has a bias due to its origin, as mentioned before. Further, Pimentel and Bricalli (2023) found that areas of high and medium densities of geological structures (such as faults and joints) are more prone to landslide occurrence in Vitória, though in areas of very high density of geological structures, where the slopes are steepest, there is “(...) little inhabitation and little or no action by the Civil Defense (...)”, which documents landslide occurrences. Still, human activities on slopes are pointed as major contributors to landslide phenomena elsewhere (Amaral, 1996; Aristizabal; Sanchez, 2020; Damm; Klose, 2015; Smyth; Royle, 2000; Xavier; Listo; Nery, 2022), and considered more influential to increase landslide frequency than climate change (Amarasinghe *et al.*, 2023; Froude; Petley, 2018).

The tests for each preparatory causal factor show that two of the man-made processes (water leakage from services, like water supply, sewage, stormwater drainage, and vegetation removal; factors 4.6 and 4.7) are not associated to landslide events, i.e., though those factors are relevant for landslide occurrence (Alcântara *et al.*, 2023; Sidle; Ochiai, 2006; Smyth; Royle, 2000), in Vitória they are not statistically significant. The highest value for the phi coefficient (i.e., the causal factor most associated with landslides) is related to defective maintenance of the drainage system (4.5 in Table 4; moderate association; φ=0.373). This highlight that, in Vitória, a poorly kept drainage system that leave stormwater flowing freely on the slope is worse for overall landsliding than punctual leaks/defects. All other factors, such as slope loading and excavation, weathered materials, and contrast in permeability, are weakly related to landslides, i.e., they have less predominance in conditioning a landslide.

Table 4 – Independency tests for landslide events and the preparatory causal factors

Preparatory causal factors[a]	X^2	Critical value	p-value	φ	Null hypothesis (independence)
1.4	31.802	9.49	0	0.241	Rejected
1.6	18.088		0.001	0.182	
1.9	26.837		0	0.221	
4.1	28.933		0	0.23	
4.2	34.375		0	0.25	
4.5	76.285		0	0.373	
4.6	4.979		0.289		Accepted
4.7	1.35		0.853		
4.8	18.771		0.001	0.185	Rejected
4.9	17.541		0.002	0.179	

[a] The codes refer to the preparatory causal factors on Table 3.
Source: by the authors.

Triggering causal factors

The main triggering causal factors of landslides in Vitória are related to rainfall (Table 5), whether prolonged high precipitation or intense, short-period, rainfall events (67.2% and 20.1% of all reports, respectively). Both types of rainfall (intense and short-duration and prolonged) act to reduce the shear strength of slope materials by reducing apparent cohesion and increasing pore water pressure. In 28 landslide reports both rainfall factors were pointed as triggers (5.1%), while in 66 landslide reports no triggers were specified (12%). Other triggering causal factors, most of them related to man-made processes, were described in less than 4% of all reports.

Table 5 – Triggering causal factors described in landslide event reports, ordered by relevance

Preparatory causal factors[a]		n	%[b]
4.5	Defective maintenance of the drainage system	21	3.8%
4.1	Excavation of the slope or at its toe	20	3.7%
4.6	Water leakage from services (water supplies sewers, stormwater drains)	7	1.3%
4.2	Loading of the slope or at its crest	3	0.6%
2.9	Deposition loading the slope crest	1	0.2%
4.7	Vegetation removal (deforestation)	1	0.2%
4.9	Creation of dumps of very loose waste	1	0.2%
4.10	Artificial vibration (including traffic, pile driving, heavy machinery)	1	0.2%
Arson		1	0.2%

[a] The first digit corresponds to the group of factors as follows: 2) geomorphological processes; 3) physical processes; and 4) man-made processes.

[b] The frequency is calculated based on the 548 event reports during the 1999-2017 period.

Source: by the authors.

By groups of triggering causal factors, physical and man-made processes have a weak association with landslide events in Vitória, although physical processes are more strongly related to landslides than man-made processes (respectively, physical processes: X^2=24.801, φ=0.213; and man-made processes: X2 =16.421, φ=0.173; with p-values < 0.005). Geomorphological processes were not tested due to the low number of cases.

Only two triggering causal factors have associations to landslides, with weak relationships. The strongest relationship was between landslide events and defective maintenance of the drainage system, followed by prolonged high precipitation (Table 6). The second most prevalent triggering causal factor in Vitória (3.1., short intense episodes of rainfall) is not statistically related to landslides.

Table 6 – Independency tests for landslide events and the triggering causal factors

Preparatory causal factors[a]	X^2	Critical value	p-value	φ	Null hypothesis (independence)
3.1	2.848		0.584		Accepted
3.3	21.643		0.000	0.199	Rejected
4.1	2.911	9.49	0.573		Accepted
4.5	26.064		0.000	0.218	Rejected
4.6	0.284		0.991		Accepted

[a] The codes refer to the preparatory causal factors on Table 5.

Source: by the authors.

Rainfall is commonly cited as main trigger for landslides (Amarasinghe *et al.*, 2023; Froude; Petley, 2018; Sepúlveda; Petley, 2015), including Colombia (Aristizabal; Sanchez, 2020), China (Li *et al.*, 2024), Germany (Damm; Klose, 2015), and Portugal (Pereira *et al.*, 2014; Zêzere *et al.*, 2014), to name a few. In Brazil, recent disasters were caused by rainfall extremes, like Petrópolis/RJ in 2022 (Alcântara *et al.*, 2023), São Sebastião/SP in 2023 (Bonini *et al.*, 2025; Coelho *et al.*, 2024) and the Rio Grande do Sul state in 2024 (Andrades-Filho *et al.*, 2025; Egas *et al.*, 2024).

In Vitória, the most commonly reported triggers are related to rainfall, though the strongest statistical relationship established was between landslide initiation and a human activity (i.e., defective maintenance of drainage systems). Further, Salaroli (2003) points out that a 4-day rainfall accumulation is crucial to landslides in Vitória, while Roza *et al.* (2023) show that the Greater Vitória Metropolitan Region presents a trend of increasing extreme rainfall in frequency and magnitude, which leads to a higher chance of flood and landslide events.

Therefore, better urban equipment conservation and repair could reduce, potentially, landslide activity, since the combination of accumulated rainfall (with a tendency of increasing frequency and magnitude) and defective drainage systems, along with the other preparatory causal factors, lead to unstable slopes in Vitória.

CONCLUSION

In this work, we compiled an archival multitemporal landslide inventory, based on geological-geotechnical reports from 1999 to 2017, detailed the landslide typologies more frequent in Vitória and their spatial and temporal distribution, and analyzed and identified their main preparatory and triggering causal factors.

The most common types of mass movements in Vitória are shallow slides and rockfalls. By testing statistical associations to the landslide events, we found that the combination of steep slopes with poorly developed soils, fractured, weathered surficial materials, long periods of rainfall, and unplanned dense slope occupancy makes Vitória prone to landslides.

Moreover, the landslides in Vitória show a clustered pattern, concentrating on the Island district, which has its landscape dominated by the Central Massif of Vitória, several coastal hills, and presents a dense urban occupancy. The flat areas around the massif and hills and the Goiabeiras district are almost free of landslide events.

The reports analyzed lacked precise information on the time of landslide events and the climatic information for Vitória was available in a daily basis. This hampered advancements on the construction of landslides triggering rainfall thresholds but allowed for correlation tests. There is a moderate positive correlation between annual rainfall and landslide events in Vitória, while the correlation found between average monthly rainfall and landslide events is also positive, but very strong. The period from November-January is the most humid and accumulates most of the landslide events reported, while the drier months (June-August) accumulate most of the inspections reported.

The associations found between landslides events and individual causal factors in Vitória range from moderate to weak, with heavy emphasis on man-made processes. Even though this could stem from a bias in the input data (i.e., the geological-geotechnical reports), the results point to the multifactorial nature of a landslide, where the event is the result of several preparatory and triggering processes and factors interacting over time and space to produce slope instability.

Future developments for landslide research in Vitória (and elsewhere in Brazil) should include other sources to the inventory, aiming to increase completeness (temporal and spatial), such as newspapers, magazines, public archives, aerial imagery, etc. The creation and maintenance of an up-to-date landslide inventory, with precise date and time of occurrences, allow the forecasting of rainfall thresholds, and the establishment of early warning and/or near-real-time alert systems. Additionally, precise information on the landslide shape, size, path, and mapping in polygon format, allow better susceptibility, hazard, and risk analysis.

Finally, understanding where and how often landslides occur in a region is a crucial first step towards developing and/or updating a risk management plan, which guides public effort to prepare for and mitigate risks, including environmental education, simulation exercises, early warning systems, and structural control measures. ●

ACKNOWLEDGMENTS

The authors thank the Municipal Department of Construction and Housing of Vitória (*Secretaria Municipal de Obras* – SEMOB/Prefeitura Municipal de Vitória) for providing the geological-geotechnical reports, the Federal University of Espírito Santo and the Postgraduate Program in Geography for their support. J.F.E. thanks the Brazilian Federal Agency for Support and Evaluation of Graduate Education (CAPES) and the Brazilian Fulbright Commission for the grants awarded during her Doctorate. E.M. thanks the Brazilian National Council for Scientific and Technological Development (CNPq) and the Espírito Santo Research Support Foundation (FAPES) for granting a state productivity research award (No. 304330/2024-8).

BIBLIOGRAPHICAL REFERENCES

ALCÂNTARA, Enner; MARENGO, José A.; MANTOVANI, José; LONDE, Luciana R.; SAN, Rachel Lau Yu; PARK, Edward; LIN, Yunung Nina; WANG, Jingyu; MENDES, Tatiana; CUNHA, Ana Paula; PAMPUCH, Luana; SELUCHI, Marcelo; SIMÕES, Silvio; CUARTAS, Luz Adriana; GONCALVES, Demerval; MASSI, Klécia; ALVALÁ, Regina; MORAES, Osvaldo; FILHO, Carlos Souza; MENDES, Rodolfo; NOBRE, Carlos. Deadly disasters in southeastern South America: flash floods and landslides of February 2022 in Petrópolis, Rio de Janeiro. **Natural Hazards and Earth System Sciences,** 23, n. 3, p. 1157-1175, 2023.

AMARAL, Cláudio Palmeiro do. **Escorregamentos no Rio de Janeiro:** inventário, condicionantes geológicas e redução do risco. 1996. 269 f. Tese (Doutorado) – Departamento de Engenharia Civil, Pontifícia Universidade Católica do Rio de Janeiro, Rio de Janeiro.

AMARASINGHE, M. P.; KULATHILAKA, S. A. S.; ROBERT, D. J.; ZHOU, A.; JAYATHISSA, H. A. G. Risk assessment and management of rainfall-induced landslides in tropical regions: a review. **Natural Hazards,** 120, n. 3, p. 2179-2231, 2023.

ANDRADES-FILHO, Clódis de Oliveira; MEXIAS, Lorenzo Fossa Sampaio; QUEVEDO, Renata Pacheco; HERRMANN, Pâmela Boelter; OLIVEIRA, Guilherme Garcia de ; CREMON, Édipo Henrique; CARGNIN, Beatriz Rosa da; REIS, Mateus da Silva; NOVAKOSKI, Kleverson Ribeiro; SANTOS, Dafne Cavalheiro dos ; SLUTER, Claudia Robbi; IESCHECK, Andrea Lopes; GUASSELLI, Laurindo Antonio; JUNIOR, Milton Ribeiro; GRUBER, Nelson Luis Sambaqui; PHILIPP, Ruy Paulo; MICHELIN, Cassiana Roberta Lizzoni; VIERO, Antonio Pedro; GONZATTI, Clovis; ROSA, Maria Luiza Correa da Câmara; BARBOZA-PINZON, Eduardo; SCHUMACHER, Raul Gick; CÁRDENAS, Sergio Mauricio Molano; SOARES, Victor Matheus; NÚÑEZ, Washington Peres; MENDONÇA, Renato Ribeiro; RIGHI DA SILVA, Mauricio Oliveira; SILVA, Michelle Cardoso da ; BRESSANI, Luis Antonio; PERES, Luana Daniela da Silva; MEVEL, Lucca Belle; DORNELES, João Igor; CACCIATORE, José Antônio; JACQUES, Felipe de Medeiros; DUARTE, Lauren da Cunha; DINIZ, Felipe de Carvalho; PETRY, Leandro; SCHWARZER, Gabriel; CARNEIRO, Marciano; GIACCOM, Bárbara. The biggest landslide event in Brazil: preliminary analysis of the Rio Grande do Sul mega disaster in May 2024. **Landslides,** 2025.

ARISTIZABAL, Edier; SANCHEZ, Oscar. Spatial and temporal patterns and the socioeconomic impacts of landslides in the tropical and mountainous Colombian Andes. **Disasters,** 44, n. 3, p. 596-618, Jul 2020.

BLAIKIE, Norman. **Analyzing quantitative data:** from description to explanation. 1 ed. London: SAGE Publications, 2003. 352 p.

BONINI, José Eduardo; MARTINS, Tiago Damas; SUGIYAMA, Marina Tamaki de Oliveira; VIEIRA, Bianca Carvalho. Landslide inventory of the 2023 Serra do Mar disaster (Brazil). **Discover Geoscience,** 3, n. 1, 2025.

BONINI, José Eduardo; VIEIRA, Bianca Carvalho; MARTINS, Tiago Damas. Semiautomatic inventory and geomorphological characterization of mass movements using high-resolution images and open-source software in the Ribeira de Iguape Valley, Brazil. **Journal of South American Earth Sciences,** 119, p. 17, 2022.

BORTOLOTI, F. D.; CASTRO JUNIOR, R. M.; ARAÚJO, L. C.; MORAIS, M. G. B. de. Preliminary landslide susceptibility zonation using GIS-based fuzzy logic in Vitória, Brazil. **Environmental Earth Sciences,** 74, n. 3, p. 2125-2141, 2015.

CABRAL, V.; REIS, F.; VELOSO, V.; CORREA, C.; KUHN, C.; ZARFL, C. The consequences of debris flows in Brazil: a historical analysis based on recorded events in the last 100 years. **Landslides,** 20, n. 3, p. 511-529, 2023.

CARDOZO, Gabriel Lopes; ZANANDREA, Franciele; MICHEL, Gean Paulo; KOBIYAMA, Masato. Inventário de movimentos de massa na bacia hidrográfica do rio Mascarada/RS. **Ciência e Natura,** 43, n. e31, p. 1-26, 2021.

CARRARA, A.; MERENDA, L. Landslide inventory in northern Calabria, southern Italy. **Geological Society of America Bulletin,** 87, n. 8, p. 1153-1162, 1976.

COELHO, Rebeca Durço; VIANA, Camila Duelis; DIAS, Vivian Cristina; GROHMANN, Carlos Henrique. Landslides of the 2023 summer event of São Sebastião, southeastern Brazil: spatial dataset. **Brazilian Journal of Geology,** 54, n. 2, 2024.

COROMINAS, Jordi; VAN WESTEN, C. J.; FRATTINI, P.; CASCINI, Leonardo; MALET, J. P.; FOTOPOULOU, S.; CATANI, Filippo; VAN DEN EECKHAUT, M.; MAVROULI, O.; AGLIARDI, Federico; PITILAKIS, K.; WINTER, Mike G.; PASTOR, M.; FERLISI, S.; TOFANI, V.; HERVÁS, Javier; SMITH, J. T. Recommendations for the quantitative analysis of landslide risk. **Bulletin of Engineering Geology and the Environment,** 73, n. 2, p. 209-263, 2014.

COUTO, Jeniffer Oliveira Nepomuceno do; EFFGEN, Julia Frederica; VIEIRA, Bianca Carvalho; SILVA, Telma; MARCHIORO, Eberval. Dynamics of mass movements in an urban basin: a case study in the Fradinhos drainage Basin, Vitória, Espírito Santo, Brazil. **Natural Hazards,** 2024.

DAMM, Bodo; KLOSE, Martin. The landslide database for Germany: Closing the gap at national level. **Geomorphology,** 249, p. 82-93, 2015.

DIAS, Helen Cristina; HÖLBLING, Daniel; DIAS, Vivian Cristina; GROHMANN, Carlos Henrique. Application of Object-Based Image Analysis for Detecting and Differentiating between Shallow Landslides and Debris Flows. **GI_Forum,** 1, p. 34-44, 2023.

EFFGEN, Julia Frederica; ROCHA, Pablo de Azevedo; PIRES, Patrício José Moreira; MARCHIORO, Eberval. Geotechnical parametrization for shallow landslide modelling in Fradinhos, Vitória, Espírito Santo - Brazil. **Sociedade & Natureza,** 32, p. 711-727, 2020.

EGAS, Harideva Marturano; STABILE, Rodrigo Augusto; DE ANDRADE, Marcio Roberto Magalhães; MICHEL, Gean Paulo; DE ARAÚJO, João Paulo Carvalho; MICHEL, Rossano Dalla Lana; MENDES, Tatiana Sussel Gonçalves; NERY, Tulius Dias; DE PAULA, Danielle Silva; RECKZIEGEL, Elisabete Weber. Comprehensive inventory and initial assessment of landslides triggered by autumn 2024 rainfall in Rio Grande do Sul, Brazil. **Landslides,** 2024.

EHRLICH, M.; LUIZ, B. J.; MENDES, C. G.; LACERDA, W. A. Triggering factors and critical thresholds for landslides in Rio de Janeiro-RJ, Brazil. **Natural Hazards,** 107, n. 1, p. 937-952, 2021.

FELL, Robin; COROMINAS, Jordi; BONNARD, Christophe; CASCINI, Leonardo; LEROI, Eric; SAVAGE, William Z. Guidelines for landslide susceptibility, hazard and risk zoning for land use planning. **Engineering Geology,** 102, n. 3-4, p. 85-98, 2008.

FROUDE, Melanie J.; PETLEY, David N. Global fatal landslide occurrence from 2004 to 2016. **Natural Hazards and Earth System Sciences,** 18, n. 8, p. 2161-2181, 2018.

GUIDICINI, Guido; NIEBLE, Carlos Manoel. **Estabilidade de taludes naturais e de escavação.** 9 ed. São Paulo: Blucher, 1983. 196 p.

GUZZETTI, Fausto; MONDINI, Alessandro Cesare; CARDINALI, Mauro; FIORUCCI, Federica; SANTANGELO, Michele A.; CHANG, Kang-Tsung. Landslide inventory maps: New tools for an old problem. **Earth-Science Reviews,** 112, n. 1-2, p. 42-66, 2012.

IBGE, Instituto Brasileiro de Geografia e Estatística. **Portal de Mapas.** 2017. Disponível em: https://portaldemapas.ibge.gov.br/portal.php#homepage. Acesso em: 14/04/2025.

IBGE, Instituto Brasileiro de Geografia e Estatística. **Vitória.** 2023. Disponível em: https://cidades.ibge.gov.br/brasil/es/vitoria/panorama. Acesso em: 21 maio 2024.

IBGE, Instituto Brasileiro de Geografia e Estatística. **Censo Demográfico:** Agregados por Setores Censitários. Rio de Janeiro: IBGE 2024.

IBM. **IBM SPSS Statistics for Windows,** Version 26.0. Armonk, NY: IBM Corp, 2019.

IJSN, Instituto Jones dos Santos Neves. **Sistema Integrado de Bases Geoespaciais do Estado do Espírito Santo (GEOBASES).** 2015. Disponível em: https://geobases.es.gov.br/.

INMET, Instituto Nacional de Meteorologia. **BDMEP - Banco de Dados Metereológicos para Ensino e Pesquisa.** 2019. Disponível em: http://www.inmet.gov.br/portal/index.php?r=bdmep/bdmep. Acesso em: 15 jan. 2020.

KIRSCHBAUM, Dalia; STANLEY, Thomas; ZHOU, Yaping. Spatial and temporal analysis of a global landslide catalog. **Geomorphology,** 249, p. 4-15, 2015.

KOMAC, Marko; HRIBERNIK, Katarina. Slovenian national landslide database as a basis for statistical assessment of landslide phenomena in Slovenia. **Geomorphology,** 249, p. 94-102, 2015.

LI, Zhuoyang; YANG, Meihuan; QIU, Haijun; WANG, Tao; ULLAH, Mohib; YANG, Dongdong; WANG, Tianqing. Spatiotemporal patterns of non-seismic fatal landslides in China from 2010 to 2022. **Landslides,** 22, n. 1, p. 221-233, 2024.

MACHADO, Giseli Modolo Vieira; JABOR, Pablo Medeiros; COELHO, André Luiz Nascentes; ALBINO, Jacqueline. Geohistorical evolution and the new geological map of the city of Vitoria, ES, Brazil. **Ocean & Coastal Management,** 151, n. February 2017, p. 45-52, 2018.

MARCHIORO, Eberval. A incidência de frentes frias no município de Vitória (ES). **Revista ACTA Geográfica**, p. 49-60, 2012.

MARCHIORO, Eberval; SILVA, Graziani Mondoni; CORREA, Wesley de Souza Campos. A Zona de Convergência do Atlântico Sul e a precipitação pluvial do município de Vila Velha (ES): repercussões sobre as inundações. **Revista do Departamento de Geografia USP**, 31, p. 43-57, 2016.

MOÇO, Gabriella Almeida; NEGRI, Rogério Galante; PAUMPUCH, Luana Albertani; RIBEIRO, João Vitor Mariano; BRESSANE, Adriano; BORTOLOZO, Cassiano. Unsupervised Change Detection Methods Applied to Landslide Mapping: Case Study in São Sebastião, Brazil. **Transactions in GIS**, 2024.

OTT, R. Lyman; LONGNECKER, Michael. **An introduction to Statistical Methods & Data Analysis.** 7 ed. Boston: Cengage Learning, 2016. 1192-1192 p. 9781305269477.

PEREIRA, Susana; ZÊZERE, José Luís; QUARESMA, Ivânia Daniela; BATEIRA, Carlos. Landslide incidence in the North of Portugal: Analysis of a historical landslide database based on press releases and technical reports. **Geomorphology**, 214, p. 514-525, 2014.

PIMENTEL, Thiago Borini; BRICALLI, Luiza Leonardi. The Relationship between Lineament Patterns and Mass Movements in the Municipality of Vitória (Espírito Santo, Southeast Brazil). **Sociedade & Natureza**, 2023.

PMV, Prefeitura Municipal de Vitória. **Carta Geotécnica de Vitória.** Vitória: Prefeitura Municipal de Vitória - PMV 2014.

PMV, Prefeitura Municipal de Vitória. **Espaços protegidos do Município de Vitória – ES.** Vitória, 2023. Disponível em: sistemas7.vitoria.es.gov.br/GeoWebApi/Downloads/pdf/meioambiente/Espaco_Protegido_marco_23_A0.pdf. Acesso em: 14 fev. 2022.

POPESCU, M. E. A suggested method for reporting landslide causes. **Bulletin of the International Association of Engineering Geology**, 50, n. 1, p. 71-74, 1994.

POURGHASEMI, Hamid Reza; TEIMOORI YANSARI, Zeinab; PANAGOS, Panos; PRADHAN, Biswajeet. Analysis and evaluation of landslide susceptibility: a review on articles published during 2005–2016 (periods of 2005–2012 and 2013–2016). **Arabian Journal of Geosciences**, 11, n. 9, p. 193-193, 2018.

PROJETO MAPENCO, Projeto de Mapeamento de Áreas de Risco Geológico-Geotécnico e Monitoramento de Encostas do Município de Vitória. Laudos Geológico-Geotécnicos (1999-2018). Vitória: FEST 2018.

QGIS.ORG. *QGIS* **Geographic Information System.** 3.42 ed. QGIS Development Team, 2025.

REICHENBACH, Paola; ROSSI, Mauro; MALAMUD, Bruce D.; MIHIR, Monika; GUZZETTI, Fausto. A review of statistically-based landslide susceptibility models. **Earth-Science Reviews,** 180, n. November 2017, p. 60-91, 2018.

ROZA, Mariza Pereira de Oliveira; CECÍLIO, Roberto Avelino; ZANETTI, Sidney Sara; ABREU, Marcel Carvalho; LYRA, Gustavo Bastos; REIS, Guilherme Barbosa. Natural disasters related to rainfall trends in Espírito Santo, southeastern Brazil. **Theoretical and Applied Climatology,** 155, n. 2, p. 1451-1466, 2023.

SALAROLI, Iramaya Sepulcri. **Movimentos de massa no município de Vitória-ES:** inventário, caracterização e indicativos de um modelo comportamental. 2003. 144 f. Dissertação (Mestrado) - Programa de Pós-Graduação em Engenharia Ambiental, Universidade Federal do Espírito Santo, Vitória.

SEPÚLVEDA, S. A.; PETLEY, D. N. Regional trends and controlling factors of fatal landslides in Latin America and the Caribbean. **Natural Hazards and Earth System Sciences,** 15, n. 8, p. 1821-1833, 2015.

SGB, Serviço Geológico do Brasil. CARTA GEOLÓGICA - Folha SF-24-V-B-I Vitória. Brasília: Companhia de Pesquisa de Recursos Minerais**:** 1 p. 2014.

SIDLE, Roy C.; OCHIAI, Hirotaka. **Landslides:** Processes, Prediction, and Land Use. Washington DC: American Geophysical Union, 2006. 312 p. (Water Resources Monograph, v. 18).

SILVA, Bruce Francisco Pontes da; RAMOS, Hugo Ely dos Anjos; SILVA, José Geraldo Ferreira da; HOLLANDA, Maycon Patricio de. Chuva extrema: o caso de dezembro de 2013 no Estado do Espírito Santo. **Incaper em Revista,** 4-5, n. January 2014, p. 113-121, 2014.

SMYTH, Conor G.; ROYLE, Stephen A. Urban landslide hazards: Incidence and causative factors in Niteroi, Rio de Janeiro state, Brazil. **Applied Geography,** 20, n. 2, p. 95-118, 2000.

SUGIYAMA, Marina Tamaki de Oliveira; BONINI, José Eduardo; MARTINS, Tiago Damas; GOMES, Maria Carolina Villaça; PEREIRA, Susana; VIEIRA, Bianca Carvalho. Statistically-based regional landslide susceptibility assessment in the UNESCO global geopark Caminhos dos Cânions do Sul (Brazil). **Natural Hazards,** 2025.

VAN WESTEN, Cees J.; CASTELLANOS, Enrique; KURIAKOSE, Sekhar L. Spatial data for landslide susceptibility, hazard, and vulnerability assessment: An overview. **Engineering Geology,** 102, n. 3-4, p. 112-131, 2008.

XAVIER, Joaquim Pedro de Santana; LISTO, Fabrizio de Luis Rosito; NERY, Tulius Dias. Landslides in the State of Pernambuco. **Mercator,** 21, n. 1, p. 1-16, 2022.

ZÊZERE, J. L.; FERREIRA, A. B.; RODRIGUES, M. L. Landslides in the North of Lisbon Region (Portugal): Conditioning and triggering factors. **Physics and Chemistry of the Earth, Part A: Solid Earth and Geodesy,** 24, n. 10, p. 925-934, 1999.

ZÊZERE, J. L.; PEREIRA, S.; MELO, R.; OLIVEIRA, S. C.; GARCIA, R. A. C. Mapping landslide susceptibility using data-driven methods. **Science of the Total Environment,** 589, p. 250-267, 2017.

ZÊZERE, J. L.; PEREIRA, S.; TAVARES, A. O.; BATEIRA, C.; TRIGO, R. M.; QUARESMA, I.; SANTOS, P. P.; SANTOS, M.; VERDE, J. DISASTER: a GIS database on hydro-geomorphologic disasters in Portugal. **Natural Hazards,** 72, n. 2, p. 503-532, 2014.

AUTHOR CONTRIBUTIONS

Julia Frederica Effgen: conceptualization; methodology; formal analysis; investigation; writing – original draft; visualization.
Eberval Marchioro: conceptualization; methodology; writing – review & editing; supervision.

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Received: 07/08/2025
Accepted: 10/17/2025
Available online: 10/20/2025