SEVEN publicações acadêmicas

CHAPTER 55

Comparative analysis of the main disasters that occurred in the years 1988 to 2022 related to mass landslides in the municipality of Petrópolis in Rio de Janeiro, considering human, physical and environmental aspects

https://doi.org/10.56238/sevened2024.018-055

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ABSTRACT

This article was prepared from the master's thesis in civil protection and defense of the Fluminense Federal University, involving the context of mass landslide disasters in the municipality of Petrópolis, in the Mountain Region of the state of Rio de Janeiro. The period under analysis of the events was the one constant from the years 1988 to 2022. A comparative analysis was carried out between indicators and relevant points of human, physical and environmental aspects among the main disasters of the period. Then, the recurrence and common points of landslide disasters in the municipality were identified to improve the efficiency of mitigating measures and assist civil defense managers in their actions. Information was also gathered that characterizes the geological formation, topography, climate and meteorological conditions, natural conditions that make the municipality vulnerable to disasters involving landslides. The study allowed preliminary results to be reached that point to a cycle of disasters, comprised in the rainiest period in the municipality, with high rainfall. The neighborhoods of Quitandinha and Morin were identified with the highest recurrence of landslides and the climatic and geophysical vulnerability faced by the municipality. In the work, the term mega-disaster was also characterized.

Keywords: Disasters, Megadisaster, Landslides, Climate vulnerability.

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INTRODUCTION

This article is based on the final work of the course related to the research carried out in the municipality of Petrópolis in Rio de Janeiro, related to the disasters of mass landslides that occurred in the period from 1988 to 2022, according to Vianna (2024).

The work has as its starting point parameters to be observed in the disasters of the period, which were identified and standardized by relevance, which served to identify the data collected from each disaster. The parameters were: number of dead and injured, number of affected, number of displaced and homeless, affected neighborhoods, rainfall indexes, general information on landslides, emergency spending by the public sector and affected housing units.

These parameters were analyzed and compared by year of occurrences. And the result of the comparisons of the data collected are outlined and systematized according to the occurrences in the municipality of Petrópolis in the period from 1988 to 2022.

PROBLEM

What are the relevant relationships between disasters involving mass landslides in the municipality of Petrópolis, in the time frame from 1988 to 2022? .

OBJECTIVE

To promote a comparative analysis of landslide-related disasters in the municipality of Petrópolis – RJ, highlighting the human, physical and environmental aspects that contribute to the understanding of these events.

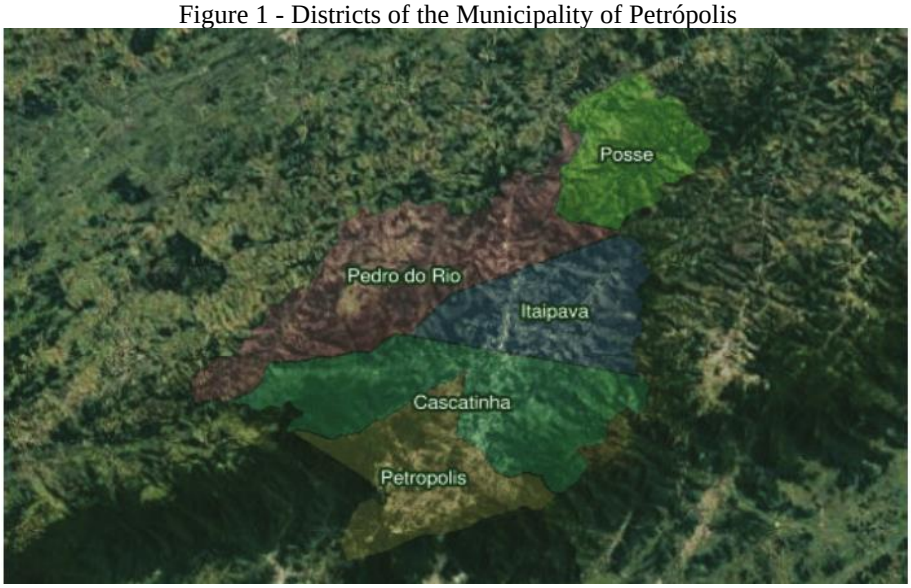
DEVELOPMENT

THE MUNICIPALITY OF PETRÓPOLIS AND CLIMATE CHANGE

The municipality of Petrópolis is located in the state of Rio de Janeiro and southeastern Brazil. It belongs to the Metropolitan Mesoregion, according to the edition of Complementary Law 184, of December 27, 2018, of the Government of the State of Rio de Janeiro (Rio de Janeiro, 2018).

The municipality is currently dismembered, according to State Law No. 1255, of December 15, 1987, of the Legislative Assembly of the State of Rio de Janeiro, into 5 districts: 1st District of Petrópolis, 2nd District of Cascatinha, 3rd District of Itaipava, 4th District of Pedro do Rio and 5th District of Posse, as shown in figure 1.

Figure 1 - Districts of the Municipality of Petrópolis



Source: Adapted from Vianna (2024).

The population of Petrópolis is 278,881 people and its territorial area is 791,144 km², according to the 2022 demographic census carried out by the IBGE and demographic density of 352.50 inhabitants per square kilometer (IBGE, 2022). The municipality belongs to the Serrana microregion of the state of Rio de Janeiro.

The municipality is 838 meters above sea level (IBGE, 2022). Its relief belongs to the Serra do Mar. According to the study by Guerra (2007) the rocks of the region are predominantly of crystalline complex, with granites, gneisses and migmatites and still present relief with great altimetric differences and steep escarpments.

Also, according to Guerra (2007) the municipality occupies a mountainous area, structured on very faulty and fractured rocks, slopes with high slopes and, at some points, soils with very deep profiles, having parts of the municipality with annual rainfall totals above 2,000 millimeters, with rainfall concentrated in the months from November to March.

According to the Chico Mendes Institute for Conservation and Biodiversity (ICMBIO, 2007), it points out that the municipality has a large Environmental Protection Area (APA-Petrópolis). In addition to this, the Serra dos Órgãos National Park and the Tinguá Biological Reserve are also part of the area. ICMBIO (2007) indicates that the surface reliefs are of the mountainous type and the steep and have high levels of rainfall and Gleisols located in fluvial plains that serve as channels for runoff from the hydrographic basins.

According to ICMBIO (2007), the main hydrographic basins of Petrópolis are the Paraíba do Sul Bay and the Guanabara Bay. Several drainage channels are formed, due to the slope, these channels become temporary rivers, due to the rains, with a large volume of water. During the rainy summer, the volume of water is formed rapidly, producing the phenomenon called "headwater" or "waterspout", which drags all kinds of material in front of it. The incidence of heavy rains in the

region can be due to the low clouds, loaded with rain, which cannot cross the summits of the mountains and clash and precipitate. Due to the steep unevenness of the slopes, the water descends at great speed, reaching the foot of the mountain with great force.

In addition to the geographical and geological characteristics of the municipality, it is observed that climate change may be related to the increase in the frequency and intensity of events that unfold disasters.

According to the Intergovernmental Panel on Climate Change - IPCC (2021), translated by the Government of Brazil, climate change is a transformation that occurs in the long term and alters temperature and climate patterns on Earth. But since the 1800s, human activities have been the main driver of climate change, contributing to the acceleration of change.

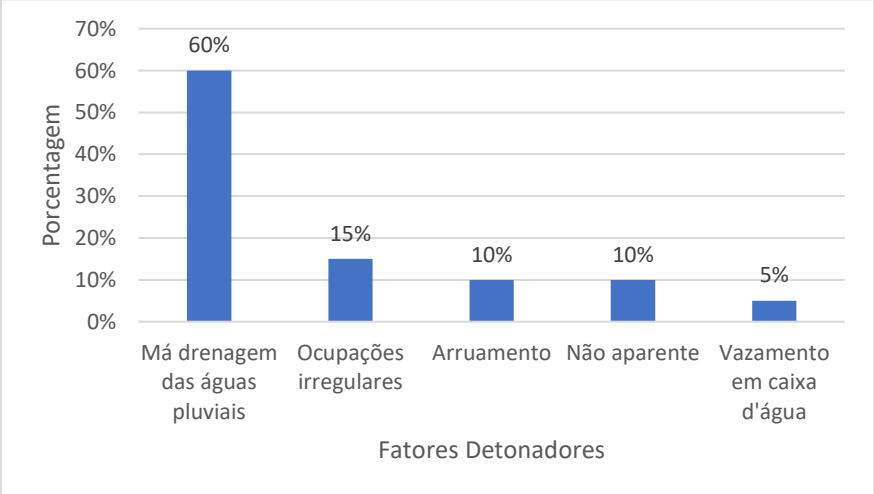
Based on this set of information and considering the characterization of the relief of the municipality, the concentration of irregular subnormal housing, the urban infrastructure, the improper use and occupation of the land and the lack of urban public planning, combined with intense rains and storms that occur very frequently in Petrópolis, fatalities occur throughout the municipal territory, in addition to material damage that impacts both the private and public sectors (Vianna, 2024).

LANDSLIDES IN THE MUNICIPALITY OF PETRÓPOLIS

Tominaga (2007) points out, in a generic way, that landslides can be understood as a series of occurrences related to the movement of soils, rocks and organic material.

Oliveira (2001), in a study on the disaster in the municipality of Petrópolis, pointed out the main agents that culminated in landslides, according to graph 1. As a result, 60% are in relation to the lack of drainage systems, often caused by irregular occupations, lack of gutters, rainwater and sewer systems, cesspools without drainage, among others.

Graph 1 - Percentage of landslide triggering factors, 2001.



Source: Adapted from Vianna (2024).

The Brazilian Atlas of Natural Disasters (CEPED, 2013) points out that the triggering factors of mass movements are directly associated with external agents, contributing to increase internal stresses.

METHODOLOGY

According to Vianna (2024), the quantitative data were collected and had the following official databases as a source of information: Brazilian Atlas of Natural Disasters from 1991 to 2012 of the University Center for Studies and Research on Disasters - CEPED, of the Federal University of Santa Catarina; the Brazilian Institute of Geography and Statistics - IBGE; the Interactive Map of the Observational Network for Natural Disaster Risk Monitoring of the National Center for Monitoring and Warning of Natural Disasters; the database of Deaths from Landslides in Brazil, 1988 to 2022, provided by the Institute of Technological Research of São Paulo - IPT; the World Bank portal, International Charter Space and Major Disasters.

The database of the municipality of Petrópolis, the Master Plan of the City of Petrópolis, the Municipal Plan for Risk Reduction – PMRR of Petrópolis of the year 2017; the portal of the Ministry of Agriculture and Livestock, through INMET (National Institute of Meteorology); and the portal of the Geological Service of Brazil - CPRM.

The work also gathered data from scientific articles, magazines, municipal and federal laws, whose indicators were assessed based on the use of comparative analysis between disasters that occurred in the period from 1988 to 2022, as follows.

DISASTERS THAT OCCURRED IN PETRÓPOLIS IN 1988

Heavy rains hit the municipality, in February 1988, 134 people died in the municipality of Petrópolis, according to Fernandes (2021). Heavy rains caused disasters throughout the territory, among the disasters were flash floods, floods, landslides, and house collapses.

According to a report by Jornal Nacional (2022), a landslide buried about nine residences on Casimiro de Abreu street, downtown, there were 40 deaths on that street alone.

According to the newspaper Diário de Petrópolis (Fernandes, 2021) the tragedy affected different parts of the city, from irregular occupations to luxury housing. The scene was one of destruction and mourning: missing people, hundreds of homeless, bodies found and unidentified.

Wernke (2021, apud Veja Magazine, 1988) points to 200 fatalities, more than 600 injured, 1000 homeless and 4000 homeless, the mayor of the city at the time reported that the rain forecast for one year, fell in just one week. At the time, the mayor decreed a state of public calamity throughout the municipality.

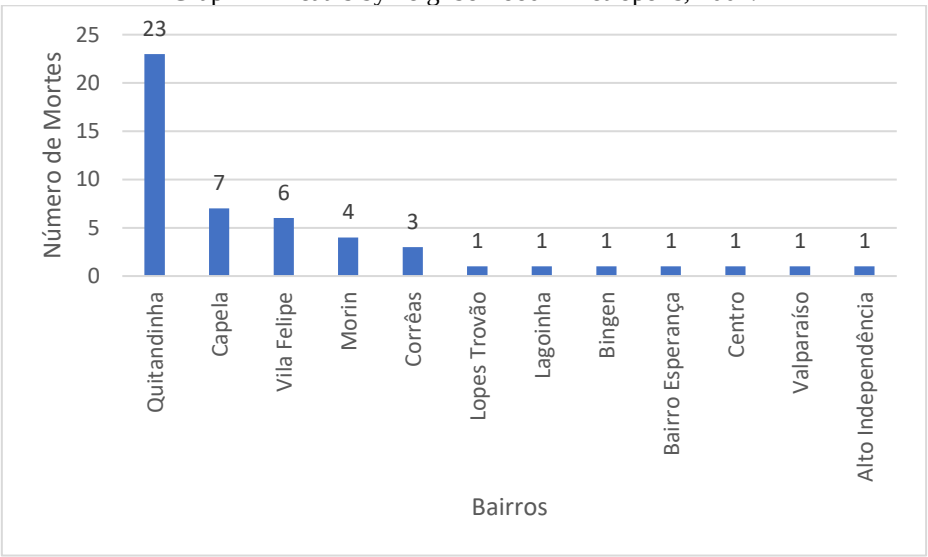
For the disaster of 1988 there are few records, the main sources of data were reports and

magazines, the EM-DAT database was consulted, which also presented divergent records.

DISASTERS THAT OCCURRED IN PETRÓPOLIS IN 2001

Heavy rains hit the municipality between February 23 and 24. 190 millimeters of rainfall were recorded in 12 hours, while in the entire month of January it recorded 179.54 millimeters, in the same year, according to Oliveira (2001). It also points out that the heavy rains were the cause of hundreds of landslides, mainly in the first and second districts of the city. It concludes that the main factors that originated the mass movements of that year were deforestation, occupations in areas without sanitation infrastructure, and with slopes greater than 45 degrees. Graph 2 points to the neighborhoods with the highest number of deaths in Petrópolis in 2001.

Graph 2 - Deaths by neighborhood in Petrópolis, 2001.



Source: Adapted from Vianna (2024).

The EM-DAT database points to the number of 50 deaths. Oliveira (2001) that had deaths in 12 neighborhoods of the city, only in the Quitandinha neighborhood, 23 deaths were identified. Due to the tragedy, a state of public calamity was declared in the municipality.

According to Soares (2001), the then president of the republic also pointed out the lack of desilting of rivers and canals in the region, an attribution of the state government. The report points out that several parts of the city landslides occurred, and the most affected neighborhoods were Valparaíso, Quitandinha, Bigen and Alto da Serra, where landslides caused deaths.

DISASTERS THAT OCCURRED IN PETRÓPOLIS IN 2011

Heavy rains hit the municipality of Petrópolis on January 11 and 12, 2011. Petrópolis has declared a state of public calamity.

According to Amaral and Lima (2011), the event occurred due to air masses coming from the South Atlantic Convergence Zone in the Mountain Region of Rio de Janeiro, combined with previous rainfall and fluvial and rainwater erosion, which culminated in landslides and floods in the region, and associated with the irregular use of land occupation resulted, in what is considered, the worst disaster ever recorded in the region.

According to Busch and Amorim (2011), several regions of the municipality of Petrópolis had records of mud and floods, several houses were affected and people were buried. Bridges, roads and streets were damaged, it also affected the geography of the city, where rivers and canals changed course. It also points out that the records of those affected (until March 23) were 905 dead, 345 missing, 34,600 homeless or displaced people throughout the mountainous region.

The World Bank (2011) classified the event as the worst disaster recorded in the history of Brazil. According to the Disaster Information Form (FIDE) of the National System of Civil Protection and Defense (SINPDEC), 74 deaths, about 25 injured, 6,956 displaced, 187 homeless and about 7,269 affected were recorded in the municipality of Petrópolis.

Those affected in the municipality of Petrópolis were mainly concentrated in the Cuiabá Valley and region. Vale do Cuiabá is a region of Itaipava, 3rd district of Petrópolis, which borders another municipality, Teresópolis. The neighborhood is about 40 km away from the center of Petrópolis. The heavy rains began on the night of January 11, which entered the early morning of the 12th.

According to a publication in the newspaper Diário de Petrópolis, on January 11, 2011, a flood of mud and water, caused by heavy rain and landslides, linked to the overflow of the Santo Antônio River, destroyed houses, dragged cars and caused floods, without distinguishing areas, social classes and people by age groups. The region had not experienced a similar tragedy since 1988. Melo (*et al*, 2011) points out that the most affected area of Petrópolis was the region in the Cuiabá River Basin, on the Santo Antônio River, with block races in the upper and middle courses and generalized flooding in the lower course of the river, and also counted in the area, 80 disappeared, for which, in 2015, there is still no solution

In its annual report on disasters, the National Center for Risk and Disaster Management - CENAD (2022) states that the tragedy was not worse only because the landslides did not affect the areas with the highest population density in Petrópolis.

According to information from the DRM-RJ (Department of Mineral Resources of Rio de Janeiro), the entry of air masses from the South Atlantic Convergence Zone (SACZ) in the Mountain Region of Rio de Janeiro, associated with the irregular use of land occupation, as well as previous rains and river and rainfall erosion, culminated in landslides and floods in the municipality of Petrópolis.

The Department of Mineral Resources of the State of Rio de Janeiro (DRM-RJ) prepared a geological report after the disaster, entitled "Serra Megadisaster". The report said the land avalanches reached 180 km/h, and moved 1 km in 20 seconds. The region was left without electricity, drinking water and communications of any kind. Public buildings and hospitals were damaged. Rescuers operate without the use of cell phones, satellites or radios. Bataglin (2014) points out that atmospheric instability resulted in heavy rains, and consequently in floods and landslides that hit rural and urban areas, some becoming totally isolated, destroying buildings and homes, public infrastructure, bridges were destroyed and the main access roads were totally or partially affected, health facilities and schools, mainly compromising water supply services, electricity and fixed telephony. Economic activities in the region were also affected, such as industries, livestock, agriculture and commerce (Freitas, 2012).

DISASTERS THAT OCCURRED IN PETRÓPOLIS IN 2013

Heavy rainfall devastated the municipality of Petrópolis on March 17, 2013. According to a study by the Department of Mineral Resources (DRM-RJ), the precipitation was marked by the joint action of the South Atlantic Convergence Zone and a cold front from the Southwest, causing heavy rains, with high rainfall, and thus saturating the soil layer leading to the occurrence of widespread landslides, flash floods, floods and several flooding points in the municipality.

The 30 days prior to the disasters kept the accumulated rainfall below average, with the accumulated rainfall below 270 millimeters.

On March 17 and 18, the Quitandinha Station recorded the highest accumulation in 24 hours with 459.5 millimeters of rain, according to table 1 (Simão, 2013).

Table 1 - Rainfall recorded on March 17 and 18, 2013

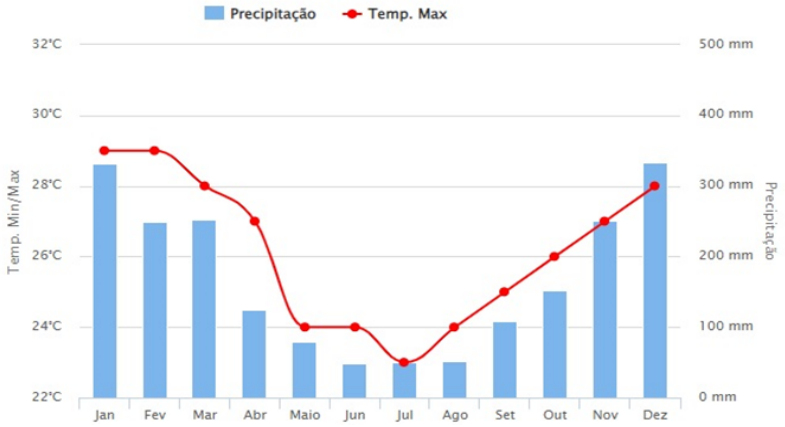
Season	24h aculates	Maximum Accumulated in 1h
Quitandinha	459,5	71,5
LNCC	405	64,25
Morin	409	42,25
Cel. Veiga	409,5	41
Bingen	337,5	35,25
Independência	355,75	66,25
Barão do Rio Branco	204,25	22
Alto da Serra	325	39,5

Source: Adapted from Vianna (2024).

The first record of rain in the municipality began at 3 pm on 03/17 and went until the early hours of March 19/03. The record of the highest rainfall occurred between 11:30 pm on 03/17, until 01 am on 03/18.

The accumulated rainfall record is equivalent from 3 pm on 03/17 to 3 pm on 03/18. Compared to the expected accumulated for the entire month of March, it is 253 millimeters, according to graph 3 Climatempo (2023), adapted from Vianna (2024).

Graph 3 - Rainfall indices and average temperatures of the municipality of Petrópolis.



Source: Adapted from Vianna (2024).

After a period with below-average rainfall, on 03/17, heavy rains hit the municipality of Petrópolis. The heavy rains originated with the influence of the heavy clouds of the Humidity Convergence Zone, which channeled a lot of moisture between the Midwest and Southeast of Brazil, and its addition to the action of humid winds coming from the ocean, a heavy rain began at night in the municipality of Petrópolis and a maximum alert for flooding of the Quitandinha River was decreed, and in Silva Jardim (at 11:00 pm, 26.4mm/h). Specifically for Petrópolis and the foot of the Serra, the Meteorology System of the state of Rio de Janeiro – SIMERJ, issued several notices of registration of significant accumulation.

These extreme rains initiated the outbreak of widespread landslides in the municipality (Department of Mineral Resources – DRM-RJ).

The most significant part of landslides reached slopes excavated upstream or downstream of houses and roads, without drainage. In most of the affected sectors, the processes began as violent erosions involving only soil, and evolved, from the deep incision of the scars, to landslides of the slopes of the ravines. Some movements reached drainage lines or amphitheaters on the slopes, occurring in the form of rubble, garbage and soil runs (sometimes rocky blocks), generated from the concentration of surface water. The natural slopes were little affected (Department of Mineral Resources – DRM-RJ).

According to the presentation of the then Secretary of Civil Defense of the municipality, Lieutenant Colonel of the Military Fire Department of Rio de Janeiro Rafael J. Simão (04/14/2013), there were more than 2,200 occurrences registered by the Civil Defense of Petrópolis, about 70% of these occurrences were landslides. The Civil Defense carried out about 2,100 inspections and

interdicted 712 houses and 662 houses were partially destroyed and 213 were completely destroyed. In addition, some health care points were affected, hindering the care of those affected and injured. As of March 25, 34 dead, 49 injured, 1085 homeless, 1,658 displaced and 150,000 people affected have been recorded.

The landslides affected several locations in the municipality, with the first district being the most affected, in the neighborhoods: Quitandinha (337 occurrences); Castrioto, Chácara Flora; Showers; Duarte da Silveira, Independência (132 occurrences); Siméria; São Sebastião (156 occurrences); Castelanea Sargento Boening (93 occurrences); Alto da Serra (215 occurrences); Meio da Serra; Caxambu; Moselle; Bamboo; Vila Felipe; Morin, Quarteirão Brasileiro, Centro (52 occurrences), 24 de Maio, 1° de Maio, Valparaíso (32 occurrences), Coronel Veiga, Bingen (80 occurrences), Quarteirão Ingelhein, Barão do Rio Branco, Floresta, Cremerie, Fazenda Inglesa, Bataillhard, Provisória, Retiro, Roseiral, Saldanha Marinho and Vila Militar. In the second district are the neighborhoods of Estrada da Saudade, Correias, Carangola, Quissamã, Itamarati, Araras, Cascatinha, Bonsucesso, Nogueiras, Samambaia and Sertão do Carangola. In the third district, Itaipava. And in the fourth district, the Pedro do Rio neighborhood (Database provided by the Office of the Comptroller General of the Union, protocol 59009.000888/2023).

According to the Department of Mineral Resources of the state of Rio de Janeiro (DRM-RJ, 2013), the month of March 2013 presented accumulated precipitation above the monthly average, mainly due to the junction of the cold fronts of the Southwest with the zones of convergence of humidity of the Northwest, resulting in a disaster of great proportions, resulting in 34 deaths and more than 100 landslides. The report points out that due to the heavy rainfall, the disaster could have been more catastrophic, due to the dry period before the event, which caused the month to start with accumulated rainfall values below average, which can be considered the main reason why the extreme rains of the seventeenth and eighteenth of March did not generate a destructive picture similar to that of the 2011 disaster in the Serra Fluminense.

DISASTERS THAT OCCURRED IN PETRÓPOLIS IN 2022

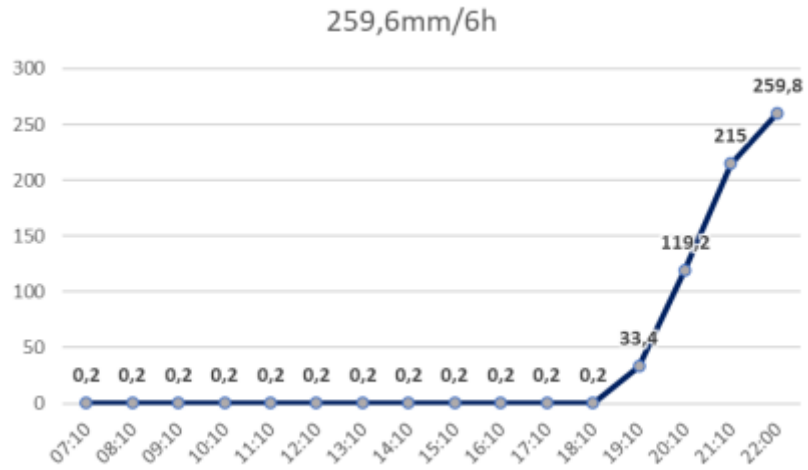
According to a report by the Department of Mineral Resources of the state of Rio de Janeiro (DRM-RJ, 2022), two major disasters were recorded that hit the municipality of Petrópolis, 35 days apart. The first, which took place on February 15, was about six hours of heavy rain, with about 260 mm of rain in the first two hours and left 234 dead, and the second event, also of heavy rain, was recorded on March 20 and left 7 dead, totaling 241 victims of disasters in the year.

Also according to DRM-RJ (2022), the State Center for Monitoring and Alerts of Natural Disasters of the State of Rio de Janeiro (CEMADEN-RJ), announced the arrival of a cold front and the pre-frontal thermodynamic effect that caused the occurrence of heavy to occasionally very heavy

rains over the municipality. The storm started around 4:30 pm, during peak congestion hours in the city, leaving the mobilization and movement of emergency and rescue vehicles impaired and difficult, and allied to this, several flooding points were recorded. The city was left without electricity and lost communications, even via cell phone, leaving a true scenario of chaos and destruction.

On February 15, the rainfall station of São Sebastião, monitored by CEMADEN, recorded 260 mm of accumulated rainfall in six hours, and 215 mm for the first three hours as shown in graph 4 (DRM-RJ, 2022). The Alto da Serra rainfall station, monitored by the State Institute of Environment (INEA), recorded 233 mm of accumulated precipitation in four hours (DRM-RJ, 2022).

Graph 4 - Accumulated rainfall per hour, in millimeters, recorded at São Sebastião station on February 15, 2022.



Source: Adapted from Vianna (2024).

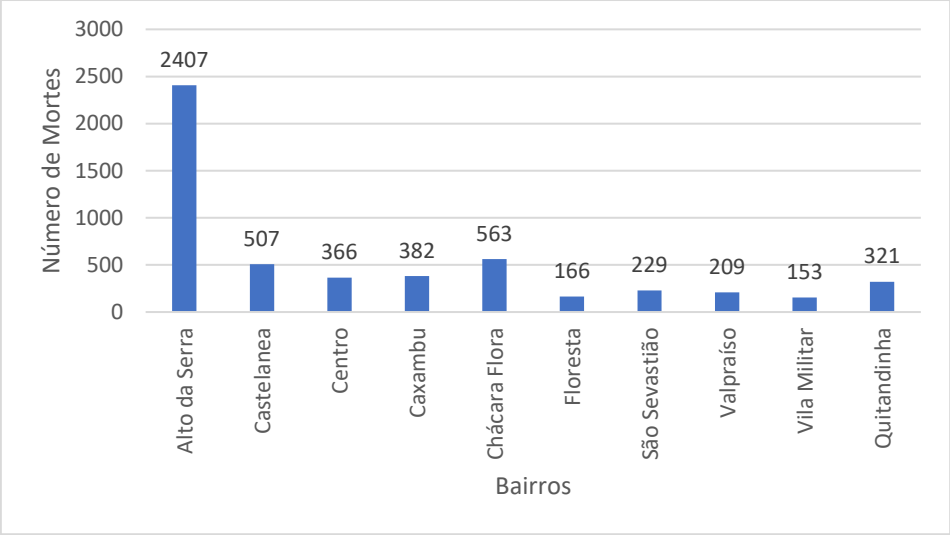
Hundreds of landslides were triggered on the slopes of the 1st District, mostly between 5 pm and 9 pm, while the city's watersheds suffered flooding processes. The region of the 1st District recorded the highest rainfall rates in the city.

Also according to the DRM-RJ (2022), the rescue and rescue actions began during the night of February 15 and were conducted by the battalion of the Petrópolis Fire Department. There were hundreds of people buried, injured and hospitalized, 6014 occurrences were registered, the number of homeless and displaced people accounted for about 3500 people, at first, the main and secondary roads, in different parts of the city, were obstructed with materials from landslides and floods, making it difficult for the Fire Department to act. Basic services to serve the population such as electricity, water, telephone and hospitals were also affected.

The high rainfall caused a rapid saturation of the surface layer of soil existing on the slopes, causing mass movements of large proportions that affected entire communities. The most affected areas of the city were the region of the 1st District, in the neighborhoods of Alto da Serra (2407 occurrences), Castelanea (507 occurrences), Centro (366 occurrences), Caxambu (382 occurrences),

Chácara Flora (563 occurrences), Floresta (166 occurrences), São Sebastião (229 occurrences), Valparaíso (209 occurrences), Vila Militar (153 occurrences) and Quitandinha (321 occurrences), according to the data presented in graph 5, according to Blaudt, Alvarenga and Garin (2023), adapted from Vianna (2024).

Graph 5 - Occurrences registered between February 15 and March 19, 2022, in the most affected neighborhoods.



Source: Adapted from Vianna (2024).

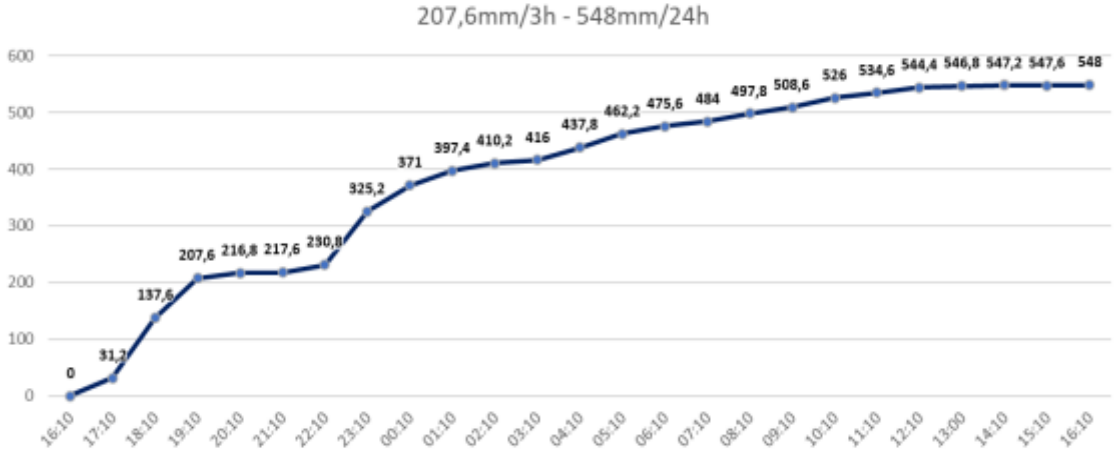
According to the authors Blaudt *et al.* (2023) 6,293 occurrences were recorded by the Municipal Civil Defense Secretariat of Petrópolis, between February 15 and March 19. Of the total, 5,394 occurrences were of properties affected by landslides or at risk of being affected, making the occurrence more frequent in the period, totaling 86%. The municipality's Civil Defense carried out 4,755 interdictions, 2,407 of which were in the Alto da Serra neighborhood alone.

Blaudt *et al.* (2023) point out that the Alto da Serra neighborhood was the most affected by the mass movement, more specifically in the locality popularly known as Morro da Oficina. The high volume of rain led to a rapid saturation of the soil layer, which slid and reached extensive talus deposits existing in the lower two-thirds of the slope. The region of the talus deposit is also the location of the buildings, this heterogeneous material was added to the mass movement, causing the displacement of rock blocks of various sizes, the complete destruction of about 90 properties and the loss of approximately 80 lives. Also according to the authors, the rescue and rescue operations, from the rains of February 15, were ended with 234 deaths among victims of landslides and drownings, of which 93 were recorded only in Morro da Oficina.

In view of the magnitude and need for specialized technical support and response infrastructure, the Municipality declared, on February 15, a state of public calamity, through Decree No. 033/2022.

On March 20, after 35 days of heavy rains on February 15, a Sunday, the Municipality of Petrópolis was again hit by heavy rains, due to the passage of a cold front over the city, culminating in new generalized mass movements in the region of the 1st District. According to the DRM-RJ report (2022), graph 6 of the DRM-RJ, (2022) the São Sebastião rainfall station, monitored by CEMADEN, had records of 207.6 mm of accumulated rainfall in three hours and about 548 mm in 24 hours.

Graph 6 - Accumulated rainfall per hour, in millimeters, recorded at São Sebastião station between March 20 and 21, 2022.



Source: Adapted from Vianna (2024).

According to the DRM-RJ report (2022), the São Sebastião rainfall station, monitored by CEMADEN, had records of 207.6 mm of accumulated rainfall in three hours and about 548 millimeters in 24 hours.

Also according to the DRM-RJ (2022), there was a reactivation of mass movement processes, due to new rainfall on March 20. The city's infrastructure and service systems for the population were still in the process of resuming normality, the Piabanha and Quitandinha rivers overflowed again, causing flooding processes in several areas of the 1st and 2nd District. With the end of the rescue and rescue actions conducted by the Fire Department, it was identified that the new disaster scenario resulted in 7 deaths, totaling 241 deaths.

RESULTS AND DISCUSSION

The data collected in the research had the purpose of explaining disasters involving mass landslides, through a comparison of data to possibly relate human and environmental factors that aggravated and triggered the disasters, with the objective of prevention and resilience of the affected society.

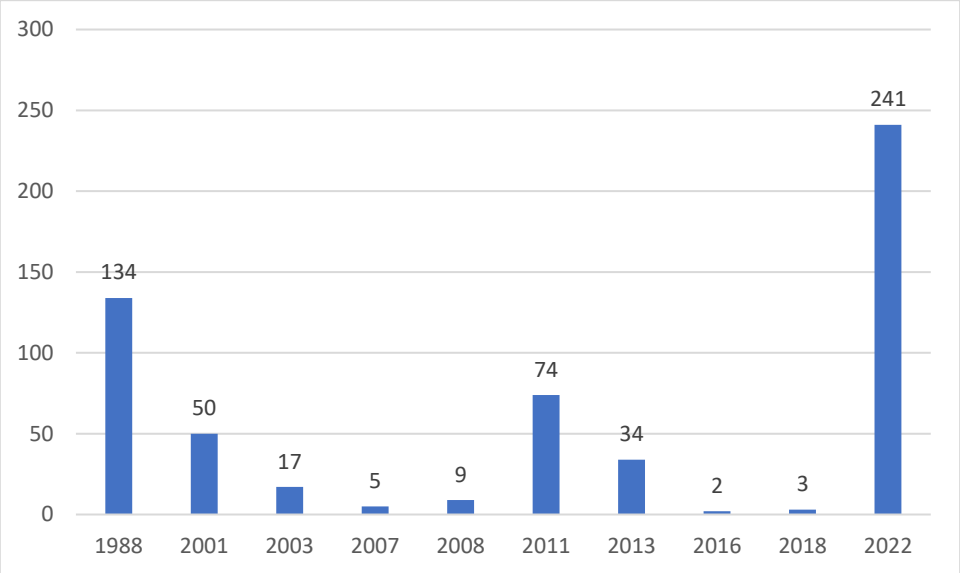
In the municipality of Petrópolis, it was possible to perceive the frequency of landslides and verify the seasonality and recurrence of these disasters. As pointed out by the PMRR (Prefeitura Municipal de Petrópolis, 2017), in addition to the geology of Petrópolis, the municipality is located

in the Brazilian humid tropical region, where the rainy season occurs in the months of October and March, with more intense rains in the summer season, between December and March. The recurrence of landslides is associated with the rainy season and heavy rains.

The municipality of Petrópolis has been facing problems of irregular occupations. According to Wernke (2021), the term irregular occupations refers to constructions in areas of environmental prevention, such as slopes and river banks, occupations in places that do not comply with local regulations. It also points out that population growth, lack of affordable housing, poverty and other socioeconomic factors are directly responsible for the increase in irregular occupations. In Petrópolis, irregular occupations occur, for the most part, in risk areas, such as slopes or river banks, increasing the vulnerability of these communities to natural disasters, such as landslides and floods.

With the data collected, it was possible to compare the number of fatalities in disasters that involved mass landslides, as shown in graph 7 (Vianna, 2024). The graph was prepared from data obtained by the IPT database in conjunction with the EM-DAT database. Thus, the disasters with the highest number of victims were the years 1988, 2001, 2011, 2013 and 2022.

Graph 7 - Number of deaths from disasters, by year, in the period from 1988 to 2022.



Source: Adapted from Vianna (2024).

It is worth mentioning that in 2013 the climatic event did not result in a greater number of victims, as the affected region was in a rural area, with low population density, but with an intensity equal to or greater than in 2011. Ottero (2018) considers the events of the years 2011 and 2013 as events with accentuated or extreme rainfall indexes.

Also according to the graph, it is not possible to say that the harmful events in the municipality are gradually increasing, but it is possible to observe the conditioning of extreme events in the region, causing great damage and contributing to the increase in the general average of the data.

Chart 2, according to Vianna (2024), containing data and information on the characteristics of the disasters analyzed, was built through the database gathered from *The International Disaster Database* - EM-DAT, the database of the Institute for Technological Research - IPT, the Digital Atlas of Disasters in Brazil, the Disaster Information Forms - Fide provided by the National System of Civil Protection and Defense - SINPDEC and the book "Occurrences of Natural Disasters from 2000 to 2012: Annual Data on Floods and Landslides by Municipality and Hydrographic Region, VOL II, published by the State Institute of the Environment - INEA.

Table 2 - Characteristics of the main disasters in the municipality of Petrópolis, in the period from 1988 to 2022.

Year	**1988**	**2001**	**2011**	**2013**	**2022**
Date	05/02/1988	23/12/2001	11/01/2011	17/03/2013	02/15/2022 and 03/20/2022
Rainfall Index	Not pointed	190mm in 12 hours	130mm in 24 hours	459.5mm in 24 hours	548mm in 24 hours
Classification (COBRADE)[4]	-	-	12200	11321	13214
Subtype (COBRADE)	Plots/Slips	Plots/Slips	Floods	Slips	Local/Convective Storm - Heavy Rainfall
Dead	134	50	74	34	241
Wounded	600	196	25	49	40
Evicted	1000	5187*	6956	1120	9465
Homeless	4000	-	187	1074	3709
Affected	-	5363	7269	152277	193458
Damage to the Public Sector	-	R$ 22.736.889,5 **	R$ 66.974.505,7 ***	R$ 41.060.500,00	R$ 23.100.000,00
Damaged/Destroyed Housing	-	-	-	875	3258
Neighborhoods	Center, Morin, Alto da Serra, Quitandinha, Bingen, Araras and Côrreas.	Quitandinha, Vila Felipe, Morin, Capela, Côrreas.	Itaipava and Vale do Cuiabá.	The 1st, 2nd, 3rd and 4th districts. Most affected Quitandinha.	Alto da Serra, Castelanea, Centro, Caxambu, Chácara Flora, Floresta, São Sebastião, Valparaíso, Vila Militar and Quitandinha.
Causes	Heavy Rains	Heavy Rains	Heavy Rains	Heavy Rains	Heavy Rains

Source: Adapted from Vianna (2024).
*. Value for homeless and displaced.
**. Equivalent values for the entire month of December.
***. Equivalent values for the entire month of January.
- . No data available.

[4] Brazilian Classification and Coding of Disasters. MIN Ordinance 260/2022.

The months in which the disasters occurred were: January (01), February (02), March (02) and December (01), for the disaster of the year 2022 it was considered an event for the month of February and an event for the month of March, thus having a total of six occurrences of the disasters. The months correspond to the summer season, the period when the highest rainfall rates occur in the municipality. The days of the disasters were variable at the beginning, middle and end of the month. With this, it is noticeable to admit the cyclicality in which major events take place in the municipality. This is the starting point for the discussion, through a comparative analysis of the disasters that occurred, as detailed below.

The main causes of the selected disasters were heavy rains, where a characteristic of the disasters was the concentration of large rainfall in a short period of time, between 12 and 24 hours.

The typifications of disasters by COBRADE in Brazil (2022) were possible in the years 2011, 2013 and 2022, in the other years they were obtained through EM-DAT. The subtype of disasters were: flash floods/landslides, flash floods, landslides and storm/heavy rains.

The year 2022 had the highest number of deaths (241) and the penultimate year in number of injuries (40). The same year also had the highest number of displaced and homeless people, totaling 13,174 people and also with the highest number of affected people, 193,458 people, followed by 2013, with 152,227 people.

With the year 2022 having the greatest consequence in terms of human losses, it presented the penultimate number with emergency expenses caused in the public sector with R$23,100,000.00 and the year 2011 with the highest expenditure, with R$66,974,505.70.

The most affected neighborhoods were those in the region of the first district, being affected in almost all, with the exception of the disaster in 2011, where heavy rains occurred, but reached a rural area of the municipality, which is far from the center.

Regarding the neighborhoods most affected, the most affected by landslides were Quitandinha and Morin, both belong to the first district. According to Ambrósio (2008, p. 96) the Quitandinha neighborhood has 12,703 residents and still has a great tourist attraction, such as the Quitandinha palace, while the Morin neighborhood has 5,095 residents and has as its strong point the concentration of the textile industry.

The DRM classified the disaster of 2011 as a "Megadisaster" in the mountainous region, however, with the data collected in the present work, it was possible to identify the years 1988, 2001, 2013 and 2022 with the same climatic and meteorological conditions, high rainfall, widespread landslides and major floods. The disasters of these years presented the same conditions as the "Megadisaster", with widespread landslides and heavy rainfall.

CONCLUSION

The municipality of Petrópolis has a great altimetric variety of mountains and steep slopes, with shallow soil layers and fractured rocks, and also high rainfall. The municipality also suffered from the process of urban sprawl, directing the construction of residences in places considered risk areas, far from the center, with little or no public infrastructure, environmental protection areas, river banks and on slopes.

The conjuncture of demographic densification factors, urban sprawl, lack of public infrastructure, meteorological conditions (high rainfall), geological formation (shallow layer of soil), combined with constant climate change, makes the municipality of Petrópolis vulnerable to disasters. Such a context leaves the population more exposed to danger. In other words, the municipality is physically exposed to a threat of disaster.

In this context, it was essential to record the data that were compared in the years listed, related to the disasters, so that a specific analysis of the consequences of the disasters, recurrence, social, environmental and physical aspects becomes viable. In a way that can subsidize public policies, structural and non-structural interventions, preparation and planning, capable of minimizing or eliminating material losses and especially human lives.

Another important point identified, by the comparison made, were the neighborhoods of Quitandinha and Morin, as the most affected by landslides and deaths. As a result, it is necessary to quickly adopt preparatory measures to reduce losses in future events.

For the municipality of Petrópolis, in the first place, it is necessary to understand, on the part of federal, state, regional and municipal managers, and also of the entire population, that there is a climatic and geophysical vulnerability to landslides and the formation of floods and floods.

With the observation of the data, it was verified an urgent aspect in the municipality must have the correct use of the soil and its occupation, in addition to the need to adopt preventive measures to improve the flood systems in the municipality, such as drainage, desilting of rivers and streams.

The term Megadisaster, by the research, was adopted in reference to the disasters that occurred in Petrópolis, in the year 2011, where by the comparison elaborated, it was verified, finally, that the disasters that occurred in the years 1988, 2001, 2013 and 2022, had similar climatic and meteorological conditions.

It is concluded that the present work addressed the main aspects and conditions of disasters that have already occurred in the municipality, contributing to future work, in order to disseminate the culture of disaster prevention throughout the national territory and that these occurrences are not forgotten in the history of Petrópolis and are scientific paradigms for the large area of civil defense.

REFERENCES

1. Aires, M., et al. (2020). Simulação numérica do desastre de origem natural ocorrido em janeiro de 2011 no Município de Nova Friburgo, RJ, utilizando o Modelo Brams. *Caminhos de Geografia, 21*(74), 259-275. EDUFU - Editora da Universidade Federal de Uberlândia. http://dx.doi.org/10.14393/rcg217449994

2. Alcântara, T. (2024). Deslizamentos mataram 4.219 pessoas no Brasil nos últimos 35 anos. *Metrópoles*. Disponível em: <https://www.metropoles.com/brasil/deslizamentos-mataram-4-219-pessoas-no-brasil-nos-ultimos-35-anos>. Acesso em 7 de janeiro de 2024.

3. Amaral, C., & Lima, I. (2011). *RISCO REMANESCENTE A ESCORREGAMENTOS ASSOCIADOS AO MEGADESASTRE 11 DA SERRA FLUMINESE: situação de Nova Friburgo*. Rio de Janeiro: DRM-RJ.

4. Ambrozio, J. C. G. (2008). *O presente e o passado no processo urbano da cidade de Petrópolis (Uma história territorial)* (Tese de doutorado). Faculdade de Filosofia, Letras e Ciências Humanas, Universidade de São Paulo, São Paulo, SP.

5. Banco Mundial. (2012). *Avaliação de perdas e danos: Inundações e deslizamentos na região serrana do Rio de Janeiro - janeiro de 2011*. Brasília: Editora Executiva.

6. Bataglin, L. M. C., et al. (2014). O problema de localização-distribuição no megadesastre da região Serrana no Rio de Janeiro. *Gestão & Produção, 21*(4), 865-881. FapUNIFESP (SciELO). http://dx.doi.org/10.1590/0104-530x834-11

7. Blaudt, L. M., et al. (2023). Desastre ocorrido em Petrópolis no verão de 2022: Aspectos gerais e dados da defesa civil. *Geosciences = Geociências, 42*(1), 59-71. UNESP - Universidade Estadual Paulista. http://dx.doi.org/10.5016/geociencias.v42i01.17210

8. Brasil. (2012). *Instrução Normativa nº 1, de 24 de agosto de 2012*. Brasília, DF. Disponível em: https://www.cnm.org.br/cms/images/stories/Links/09062014_Instrucao_normativa_de_01_de_agosto_de_2012.pdf. Acesso em 20 de novembro de 2023.

9. Brasil. (2012). *Lei nº 12608, de 10 de abril de 2012*. Brasília, DF. Disponível em: <https://legislacao.presidencia.gov.br/atos/?tipo=LEI&numero=12608&ano=2012&ato=cf8ETRU1kMVpWT18a>. Acesso em 12 de janeiro de 2024.

10. Busch, A., & Amorim, S. (2011). A tragédia da região serrana do Rio de Janeiro em 2011: Procurando respostas. *Casoteca de Gestão Pública*.

11. Carvalho, C. S., & Galvão, T. (Org.). (2006). *Prevenção de riscos de deslizamentos em encostas: Guia para elaboração de políticas municipais*. Brasília, DF: Ministério das Cidades/Cities Alliance.

12. Castro, A. L. C. (1998). *Glossário de Defesa Civil: Estudos de riscos e medicina de desastres*. Brasília: MPO/Departamento de Defesa Civil.

13. CEPED, UFSC, Banco Mundial, Global Facility for Disaster Reduction and Recovery, Fundação de Amparo à Pesquisa e Extensão Universitária, Universidade Federal de Santa Catarina. (2020). *Relatório de danos materiais e prejuízos decorrentes de desastres naturais no Brasil (1995-2019)* (2. ed.). Florianópolis: Fapeu.

14. Climatempo. (n.d.). *Climatologia e histórico de previsão do tempo em Petrópolis, BR*. Disponível em: <https://www.climatempo.com.br/climatologia/317/petropolis-rj>. Acesso em 12 de dezembro de 2023.

15. CPRM - Serviço Geológico do Brasil. (2013). *Relatório Anual 2013*. Brasília: Ministério de Minas e Energia. Disponível em: https://www.sgb.gov.br/publique/media/informacao_publica/rel_anual_2013.pdf. Acesso em 8 de novembro de 2023.

16. DRM-RJ. (2013). *Correlação de chuvas x escorregamentos no estado do Rio de Janeiro no mês de março de 2013*. Rio de Janeiro: Departamento de Recursos Minerais.

17. DRM - RJ. (2022). *Emergencial Petrópolis: Relatório técnico*. Rio de Janeiro: Thalweg Tecnologia e Serviços de Geotecnia. Disponível em: <https://www.drm.rj.gov.br/sites/default/files/arquivos_paginas/RL_09.2022.01-MTDLG-PETROPOLIS.pdf>. Acesso em 21 de dezembro de 2023.

18. Freitas, C. M. de, Carvalho, M. L. de, Ximenes, E. F., Arraes, E. F., & Gomes, J. O. (2012). Vulnerabilidade socioambiental, redução de riscos de desastres e construção da resiliência: Lições do terremoto no Haiti e das chuvas fortes na região serrana, Brasil. *Ciência & Saúde Coletiva, 17*(6), 1577-1586. FapUNIFESP (SciELO). http://dx.doi.org/10.1590/s1413-81232012000600021

19. G1. (2022). Quarta-feira, 16 de fevereiro. Disponível em: <https://g1.globo.com/resumo-do-dia/noticia/2022/02/16/quarta-feira-16-de-fevereiro.ghtml>. Acesso em 18 de novembro de 2023.

20. Guerra, A. J. T., Gonçalves, L. F. H., & Lopes, P. B. M. (2007). Evolução histórico-geográfica da ocupação desordenada e movimentos de massa no município de Petrópolis, nas últimas décadas. *Revista Brasileira de Geomorfologia, 8*(1), 35-43. http://dx.doi.org/10.20502/rbg.v8i1.84. Disponível em: https://rbgeomorfologia.org.br/rbg/article/view/84. Acesso em 5 de janeiro de 2024.

21. IBGE - Departamento de Geografia. (2022). *Censo demográfico 2022*. Rio de Janeiro: IBGE. Disponível em: <https://censo2022.ibge.gov.br/panorama/>. Acesso em 24 de setembro de 2023.

22. IBGE - Departamento de Geografia. (1990). *Divisão do Brasil em mesorregiões e microrregiões geográficas* (1ª ed.). Rio de Janeiro: IBGE. Disponível em: <https://biblioteca.ibge.gov.br/index.php/biblioteca-catalogo?id=22269&view=detalhes>. Acesso em 24 de setembro de 2023.

23. IBGE - Departamento de Geografia. (2023). *Proposta metodológica para classificação dos espaços do rural, do urbano e da natureza no Brasil*. Coordenação de Geografia. Rio de Janeiro: IBGE.

24. IPCC - Painel Intergovernamental sobre Mudança do Clima (Comp.). (2021). *Mudança do Clima 2021: A base científica*. [S.I.]: IPCC. Disponível em: https://www.gov.br/mcti/pt-br/acompanhe-o-mcti/sirene/publicacoes/relatorios-do-ipcc/arquivos/pdf/IPCC_mudanca2.pdf. Acesso em 4 de novembro de 2023.

25. Jornal Nacional. (2022). Volume de chuva registrado em Petrópolis (RJ) é o maior em quase um século de medições. *G1*. Disponível em: https://g1.globo.com/jornal-

nacional/noticia/2022/02/16/volume-de-chuva-registrado-em-petropolis-rj-e-o-maior-em-quase-um-seculo-de-medicoes.ghtml. Acesso em 20 de novembro de 2023.

26. Kobiyama, M., Oliveira, A. C., & Gama, A. C. (2006). *Prevenção de desastres naturais: Conceitos básicos*. Curitiba: Organic Trading.

27. Lima, A. C. de S. (2016). *Mitigação, preparação, resposta e recuperação das empresas da Região Serrana do Rio de Janeiro no desastre de 2011* (Dissertação de mestrado). Pontifícia Universidade Católica do Rio de Janeiro, Rio de Janeiro, Brasil.

28. Melo, A. B. C. de. (2011). *As chuvas podem continuar escassas no extremo sul do Brasil*. InfoClima: Boletim de Informações Climáticas do CPTEC/INPE, 18(1). Disponível em: http://infoclima.cptec.inpe.br/%7Erinfo/pdf_infoclima/201101.pdf. Acesso em 20 de novembro de 2023.

29. Oliveira, A. C. de, Soares, J. G., & Silva, M. R. (2001). *Petrópolis: Chuvas, deslizamentos e mortes em dezembro de 2001*. Universidade de Brasília.

30. Ottero, C. R., Chargel, L. T., & Hora, M. de A. G. M. da. (2018). Análise de frequência dos dados pluviométricos observados em 2011 e 2013 na Região Serrana, Estado do Rio de Janeiro. *Revista Brasileira de Meteorologia, 33*(1), 131-139. http://dx.doi.org/10.1590/0102-7786331007

31. Prefeitura Municipal de Petrópolis (Org.). (2017). *Plano municipal de redução de risco de movimentos de massa 2º distrito, Cascatinha, Petrópolis, RJ*. Petrópolis: Prefeitura Municipal de Petrópolis. Disponível em: <https://sig.petropolis.rj.gov.br/cpge/PMRR%20-%202%C2%BADISTRITO-PETR%C3%93POLIS.pdf>. Acesso em 25 de novembro de 2023.

32. Rio de Janeiro (Estado). (2018). *Lei Complementar nº 184, de 27 de dezembro de 2018*. Dispõe sobre a Região Metropolitana do Rio de Janeiro. Rio de Janeiro, RJ.

33. Rio de Janeiro. (2007). *Parque Nacional da Serra dos Órgãos: Uma visão geral*. In Parnaso. Ciência e Conservação na Serra dos Órgãos (pp. 11-23). Rio de Janeiro: Ministério do Meio Ambiente. Disponível em: <https://www.icmbio.gov.br/parnaserradosorgaos/images/stories/Vis%C3%A3o_geral_PARNASO.pdf>. Acesso em 21 de setembro de 2023.

34. Silva, F. C. (2010). *Instrumentos de comunicação de riscos como ferramenta para a diminuição da vulnerabilidade de moradores de assentamentos precários urbanos sob risco de deslizamentos* (Dissertação de mestrado). Instituto de Pesquisas Tecnológicas do Estado de São Paulo, São Paulo, Brasil.

35. Simão, R. J. (2013). *Município de Petrópolis: Incidentes dos dias 17 e 18 de março de 2013*. Rio de Janeiro: Governo do Rio de Janeiro. Disponível em: https://www2.camara.leg.br/atividade-legislativa/comissoes/comissoes-temporarias/externas/54a-legislatura/desastres-na-regiao-serrana-do-rio-de-janeiro/audiencias-publicas-1/apresentacao-do-ten-cel-rafael-simao-defesa-civil-petropolis. Acesso em 8 de dezembro de 2023.

36. Soares, P. (2001). Chuva mata 43 no Rio, 28 só em Petrópolis. *Folha de São Paulo*. Disponível em: https://www1.folha.uol.com.br/fsp/cotidian/ff2612200101.htm. Acesso em 24 de novembro de 2023.

37. Souza, L. A. de. (2015). Planejamento e controle urbanístico na prevenção e mitigação de desastres naturais. *Revista Brasileira de Direito Urbanístico | Rbdu*, 1, 51-85. http://dx.doi.org/10.55663/rbdu.v1i1.401

38. Tominaga, L. K. (2007). *Avaliação de metodologias de análise de risco a escorregamentos: Aplicação de um ensaio em Ubatuba, SP* (Tese de doutorado). Universidade de São Paulo, São Paulo, Brasil.

39. Torres, G. P., Carmo, L. F. R. do, & Palmeira, A. C. P. de A. (2020). Estudo da relação entre precipitação e deslizamentos no município de Petrópolis – RJ. *Sistemas & Gestão, 15*(1), 38-45. http://dx.doi.org/10.20985/1980-5160.2020.v15n1.1611

40. Universidade Federal de Santa Catarina. Centro Universitário de Estudos e Pesquisas sobre Desastres. (2013). *Atlas brasileiro de desastres naturais: 1991 a 2012* (2ª ed. rev. ampl.). Florianópolis: CEPED UFSC.

41. Vianna, L. E. S. (2024). *Análise dos principais desastres envolvendo deslizamento de massa no município de Petrópolis nos anos compreendidos de 1988 a 2022* (Dissertação de mestrado). Universidade Federal do Rio de Janeiro, Rio de Janeiro, Brasil.

42. Wernke, A. V. (2021). *Vazios urbanos e desenvolvimento sustentável: A política pública de habitação no município de Petrópolis e a proteção ao meio ambiente* (Dissertação de mestrado). Universidade Nove de Julho, São Paulo, Brasil.