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Study of slope stability in Petropolis (RJ) through the geophysical methods GPR and ERT

Estudo da estabilidade de taludes em Petropolis (RJ) através dos métodos geofísicos GPR e ERT

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Abstract: Slope sliding is a natural phenomenon that occurs all over the world and that can cause loss of human lives and material. Being the possibility of evaluating these risk areas through geophysical methods. In this study, the Ground Penetration Radar (GPR) and Electrical Resistivity Tomography (ERT) methods were used at .Mato Grosso Street, in the Quitandinha neighborhood, Petrópolis (RJ), which is susceptible to landslides. The GPR is based on the propagation of electromagnetic waves with frequencies between 10 and 6000 MHz, using a 200 MHz antenna for data acquisition and data processing performed in the REFLEXW program. The ERT is based on the electric potential difference of natural or artificial electric fields, 24 electrodes were used for data acquisition, with data processing in the RES2DINV program and a data simulation in the RES2DMOD program. In the results obtained, a difference between consolidated and unconsolidated soil at approximately 1.5 m depth that can generate future mass movement, as well as the presence of blocks of different sizes scattered throughout the area, were observed, being indications that the area has already suffered with landslides, as well as drainage points and water accumulation, increasing the risks of landslides. The use of geophysical methods contributes to the analysis of slope instability and helps to avoid future disasters.

Keywords: Landslides; GPR; ERT.

Resumo: O deslizamento de taludes é um fenômeno natural que ocorre em todo mundo e que pode ocasionar perda de vidas humanas e materiais. Sendo a possibilidade de se avaliar essas áreas de risco através dos métodos geofísicos. Nesse estudo foram utilizados os métodos Radar de Penetração do Solo (GPR) e Tomografia Elétrica de Resistividade (ERT) na Rua Mato Grosso, no bairro de Quitandinha, Petrópolis (RJ), a qual é suscetível a deslizamentos de taludes. O GPR é fundamentado na propagação das ondas eletromagnéticas com frequências entre 10 e 6000 MHz, sendo na aquisição dos dados utilizado uma antena de 200 MHz e o processamento de dados realizados no programa REFLEXW. O ERT é baseada na diferença de potencial elétrico dos campos elétricos naturais ou artificias, foram utilizados para aquisição de dados 24 eletrodos, com processamento de dados no programa RES2DINV e uma simulação de dados no programa RES2DMOD. Nos resultados obtidos foram constatados, diferença de solo consolidado e inconsolidado em aproximadamente 1,5 m de profundidade que pode gerar futuros deslocamentos de terra, assim como a presença de blocos de diversos tamanhos espalhados pela área, sendo indícios de que a área já sofreu com deslizamentos de terras, além de pontos de drenagem e acúmulo de água elevando os riscos de deslizamento. O uso de métodos geofísicos vem a contribuir na análise da instabilidade de taludes e ajudar a evitar futuros desastres.

Palavras-chave: Deslizamento; GPR; ERT.

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1. Introduction

The neighborhood of Quitandinha, located in Petrópolis, a city in the mountainous region of the State of Rio de Janeiro, had its origins in 1843, initially as a city planned and projected through the Köeler Plan, but the planning of Petrópolis was abandoned and throughout the years it had a messy demographic growth. The city has been affected by numerous mass movements (e.g. 2011), which affected a large part of the mountain region, causing a total of 947 deaths, of which 71 were in Petrópolis (GUERRA; JORGE, 2014). Already in2022, the number of deaths caused by this event was 238, only in Petrópolis (AGENCIABRASIL, 2022).

According to Silva (2006), the mass movement is characterized by the displacement of part of the soil, rock or a combination of both in an inclined plane, in which it suffers the action of internal and external forces, called downhill. For Varnes (1984), mass movement is characterized by exogenous geological processes that encompass the displacement of matter, such as rock, soil and debris, which can occur naturally or artificially.

Based on Highland & Bobrowsky (2008), the slipping process occurs when there is a movement of rock, soil or both, on a slope, which causes the rupture of a surface, causing a rotational slip when a curved rupture or translational slip occurs in the surface. case of a planar rupture, both cases or even other types can occur during the displacement of the moving material. The slope is the name given to the inclined surface of a mass of soil or rock, which can be natural, called a slope, or man-made, such as embankments and cuts (GERSCOVICH, 2016).

The use of geophysical methods has been widely used in studies such as: environmental, mining, hydrogeology, among others, due to their practicality, as they are non-invasive methods that allow the visualization of the soil more quickly compared to other conventional methods, such as direct tests, time optimization in data acquisition and execution. The methods being the Ground Penetrating Radar (GPR) and Electrical Resistivity Tomography (ERT) methods increasingly used in these types of studies. This work aims to verify the stability of slopes of Mato GrossoStreet, in the city of Petrópolis, through the use of geophysical methods of ERT and GPR. According to Marques (2016) this street is within the risk areas of places susceptible to landslides.

2. Materials and methods

Initially, a bibliographic study was carried out on the types and behavior of existing mass movements, as well as those that most occur in the study area. It was necessary to understand and study the geophysical methods, mainly GPR and ERT, from their theoretical foundation to their acquisition and data processing, to analyze their applicability, advantages and disadvantages for the study of slope stability verification. Based on the radargram sections of the GPR acquisition that we already had from the study area carried out by Marques (2016), and the bibliographic knowledge of the region, a theoretical pseudo-section of two-dimensional (2D) apparent resistivity was created in the free program RES2DMOD, in order to obtain a comparison with the section obtained through the acquisition of field data with the electroresistivity equipment. The data processing intersection of lines 1 and 2 of the GPR corresponded approximately to the data obtained with the ERT method.

For this type of study, GPR can be used for imaging shallow soil, rock structures, identification of buried channels and groundwater mapping, while ERT can obtain information such as ground water level, soil layer thickness, geometry and location of the basement, presence or absence of fractures, size of rock fragments and identifying preferential landslide plans, determination of contamination plumes and both in the soil and in aquifers.

2.1 GPR Method

The GPR generates a high frequency electromagnetic wave (10 - 6000 MHz) that propagates in the ground according to the electrical characteristics of the materials. After coming into contact with the material, part of the transmitted signal is reflected to a surface receiver, which is subsequently processed to generate the radargram section (figure 1). As sedimentary, metamorphic and igneous rocks are considered semiconductor or dielectric, they can be defined by three properties: electrical conductivity, dielectric permittivity and magnetic permeability. The properties of the GPR are based on Maxwell's equations, through the theory of propagation of electromagnetic waves. When disturbed, charged electromagnetic particles propagate in the environment, generating electromagnetic waves. During the mapping of Mato Grosso Street in Quitandinha, Marques (2016) used the Terra SEARch SIR (Subsurface Interface Radar) System-3000 equipment, produced by Geophysical Survey Systems Incorporated, Inc (GSSI), and a 200 MHz monostatic shielded antenna (figure 1).

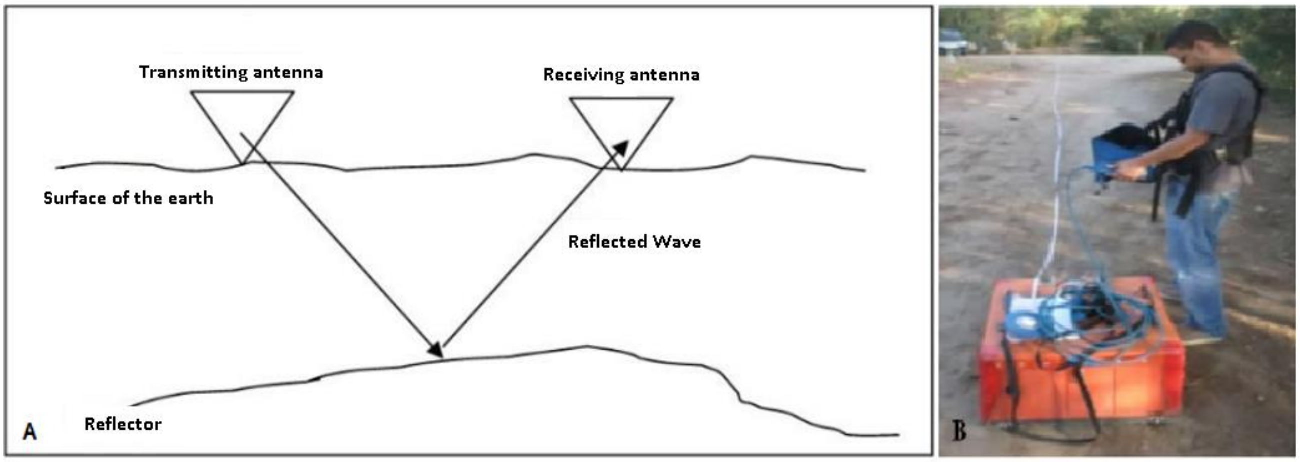

Figure 1 - Design with antenna arrangement and wave propagation in the GPR (on the left) and TerraSIRch SIR equipment (on the right).
Source: Braga (2006).

Through the acquisition of common offset data with a constant distance of 30 cm, twelve profiles were obtained in a straight line along the street, (figure 2). According to Marques (2016), for the processing of GPR data, the REFLEX – Interpex program was used, through the steps: time-zero adjustment (timezero), dewow, remove background, band-pass filter, gain (AGC Gain), 2d migration (2dmigration).

Figure 2 - GPR acquisition lines at Mato Grosso Street.
Source: Marques (2016).

In the area of line 1, the soil is extremely weathered, sandy-clay, with the presence of few rock fragments ranging from cm to meters (figure 3), as it progresses towards the area of line 2, it starts to have a reddish color (figure 3). Figure 4 shows the unprocessed and processed radargram section.

Figure 3 - (A) Location of line 1 data acquisition. (B) Reddish soil coloration of the soil.
Source: Marques (2016).

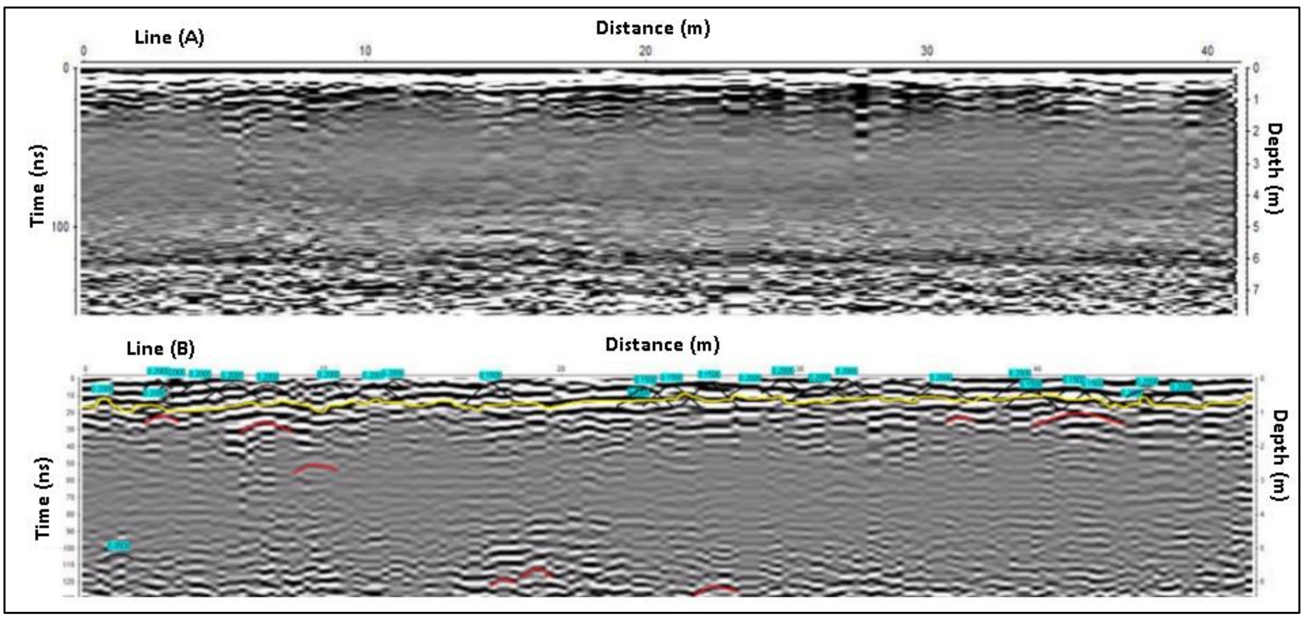

Figure 4 - (A) Unprocessed acquisition line 1 of Mato Grosso Street. (B) Line processed.
Source: Marques (2016).

In the area of line 2, the soil is sandy-clay, with a reddish color and (figure 5). In the radargram section, rock fragments of varying sizes were found, dispersed throughout the area, with the majority concentrated at depths greater than 5 m, but also fragments dispersed between 1 and 4 m in depth, with varying sizes (figure 6 A and B), with contact of sandy and friable soil varying up to 1.5 m in depth, with the data acquisition being obtained with SW-NE direction, and the section with approximately 40 meters in length.

Figure 5 - Location of line 2 data acquisition.
Source: Marques (2016).

The section perpendicularly to the slope was obtained with SW-NE direction, with approximately 40 meters in length, where in the radargram section (figures 6 A and B), it was found between 1 and 2 meters deep the contact between the friable soil and the compact soil, presence of hyperbolic shapes indicating fragments of varying sizes scattered throughout the section. Figure 6 shows the unprocessed and processed radargram section.

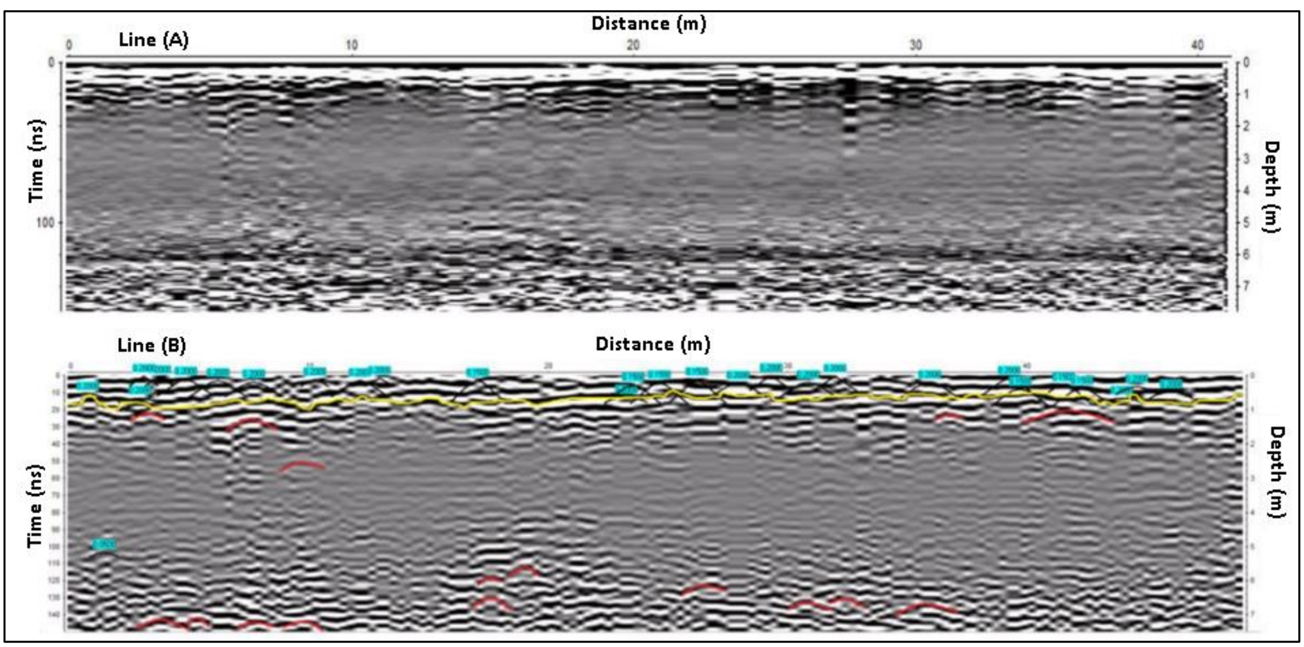

Figure 6 - (A) Line 2 unprocessed. (B) processed line. Both on Mato Grosso Street in Quitandinha.
Source: Marques (2016).

2.2 ERT Method

The ERT is based on the determination of the electrical resistivity of materials, which together with the dielectric constant and the magnetic permeability, indicate the electromagnetic properties of soils and rocks. In order to do so, a low frequency (less than 10 Hz) direct or alternating artificial electric current is used in the study area, through two electrodes located on the surface, in order to measure the potential generated between two electrodes in the vicinity of the current flow. Geological materials have properties such as electrical resistivity, which is indicative of some state characteristics in relation to some properties such as alteration, fracturing and saturation.

According to Loke (2002), and created by DEY and MORRISON (1979), the RES2MOD program is free and provided together with RES2DINV. In it, it is possible to calculate the theoretical pseudo-section of apparent resistivity for a 2D subsurface model defined by the user, with the program accepting several arrangements, and in the calculation of the apparent resistivities it is possible to use finite difference or finite element routines. The program (RES2DINV, 2003) has an inversion routine based on the least-square method with smoothness-constrained least-square inversion. One of the biggest advantages of using this method is being able to adjust according to the different types of data that you want to obtain, based on the damping and leveling factors of the filters.

The acquisition of ERT data was performed using the Syscal kid Switch-2 electroresistivity equipment with 24 electrodes, based on the dipole-dipole arrangement, using the electrical path technique with a spacing between the electrodes of 2 m. The data simulation performed in the RES2DMOD program was performed in order to assist in the interpretation of the geophysical data, the section chosen for creating the model was approximately 98 m long based on the junction of the radargram sections of lines 1 and 2 (figure 4 B and figure 6 B), with a spacing between the electrodes of 2 m between them, as it is the same configuration used in the field, with the dipole-dipole array.

In the model, the contact of the basement (orange color) with the compact soil (green color) and rock fragments (yellow color) was delimited, beyond to points indicating water saturation (blue color), as they were observed during field acquisition. The resistivity values of the model were based on the resistivity of the rocks and soil found at the study site (figure 7). Obtaining a comparative parameter of interpretation between the simulated apparent resistivity section (figure 8) with the resistivity section of the field data acquisition processed in the RES2DINV program (figure 9), the results show a satisfactory geoelectric model for the interpretation of the geological model.

Figure 7 - (A) Syscal kid Switch-24 Equipment.
Source: Authors (2022).

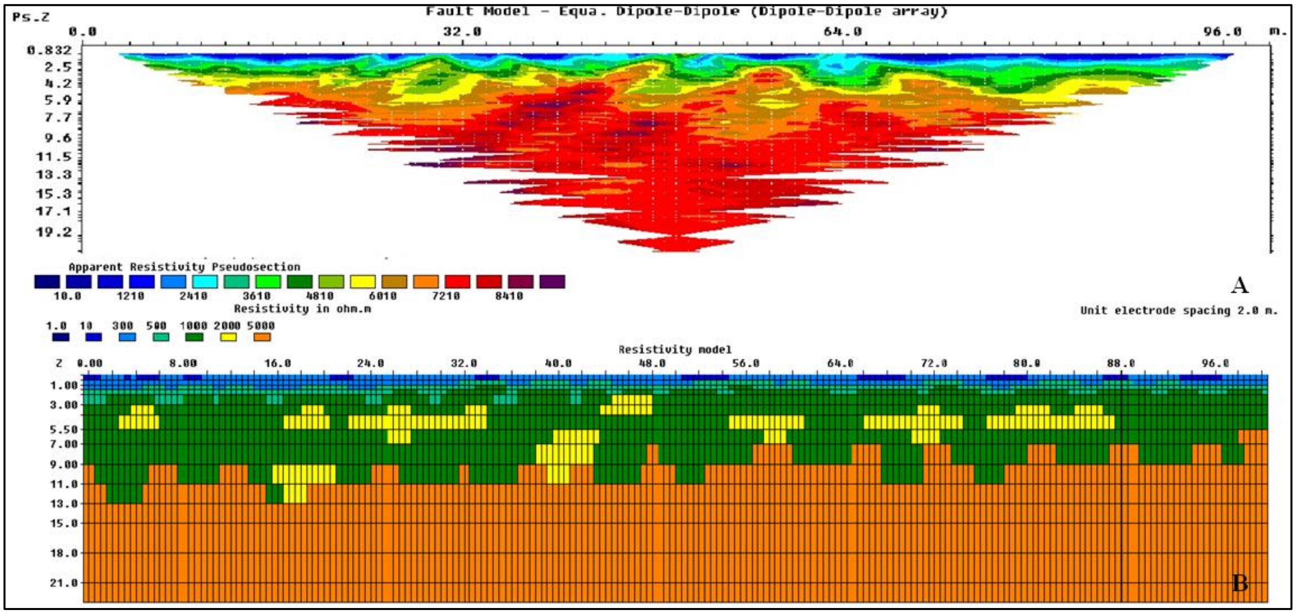

Figure 8 - (A) Pseudo-section of generated apparent resistivity. (B) Electroresistivity model made in the RES2DMOD program.
Source: Authors (2022).

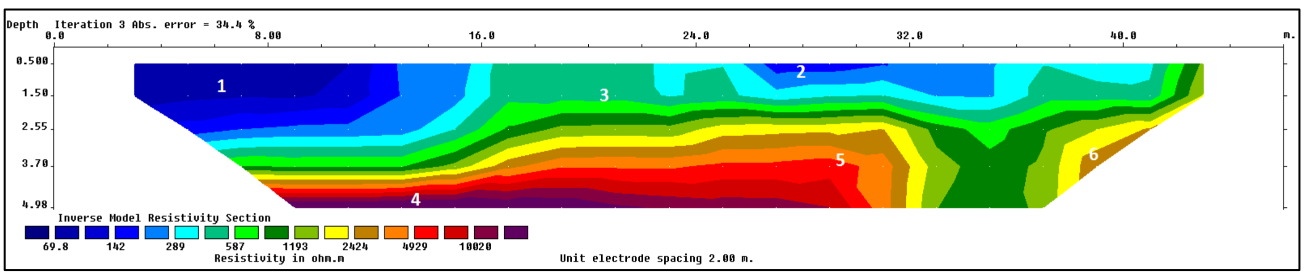

Figure 9 - Resistivity section performed on Mato Grosso Street.
Source: Authors (2022).

3. Location and characterization

The city of Petrópolis is located in the mountains, belonging to the city of Rio de Janeiro, at an altitude above 838 m, a total area of 795,798 km² which corresponds to 1.8% of the area of the State of Rio de Janeiro and 11.55% of the Mountain Region, with approximately 306,002 residents. It is bordered by São José do Vale do Rio Preto to the north, Teresópolis and Magé to the east, Duque de Caxias and Miguel Pereira to the south and Paty de Alferes, Paraíba do Sul and Areal to the west, according to IBGE (2005), shown in the figure. 10. It can also be subdivided into five districts (figure 1B), with the neighborhood of Quitandinha being located in the first, with the district having a total area of 143 km². According to Gonçalves and Guerra (2006), as it is the most populous district in Petrópolis, in addition to its physical characteristics, it is also the one with the highest number of cases related to mass movement.

The main access to the city of Petrópolis is through the BR-40, the highway that connects Rio de Janeiro to the Federal District, passing through Juiz de Fora and Belo Horizonte. However, it is also possible through the BR-495, the highway that connects the district of Teresópolis to Itaipava, to reach the BR-40. As for the Baixada Fluminense towards Petrópolis, it is possible to arrive through the RJ-107, which connects the mountains to Magé, as can be seen in figure 10. It can also be accessed by the coordinates (22°31'14"S and 43°13'5"W).

Figure 10 - Map with the main access roads to Petrópolis, with Mato Grosso Street indication.
Source: Google Earth™.

The typical vegetation cover of Petrópolis is formed by dense shoulderphilous forest due to the tropical climate, where the neighborhood of Quitandinha is delimited by the blue color, in the study site there was deforestation of the typical forest cover of the area which has superficial roots, being a factor that increases the chances of mass slippage (figure 11).

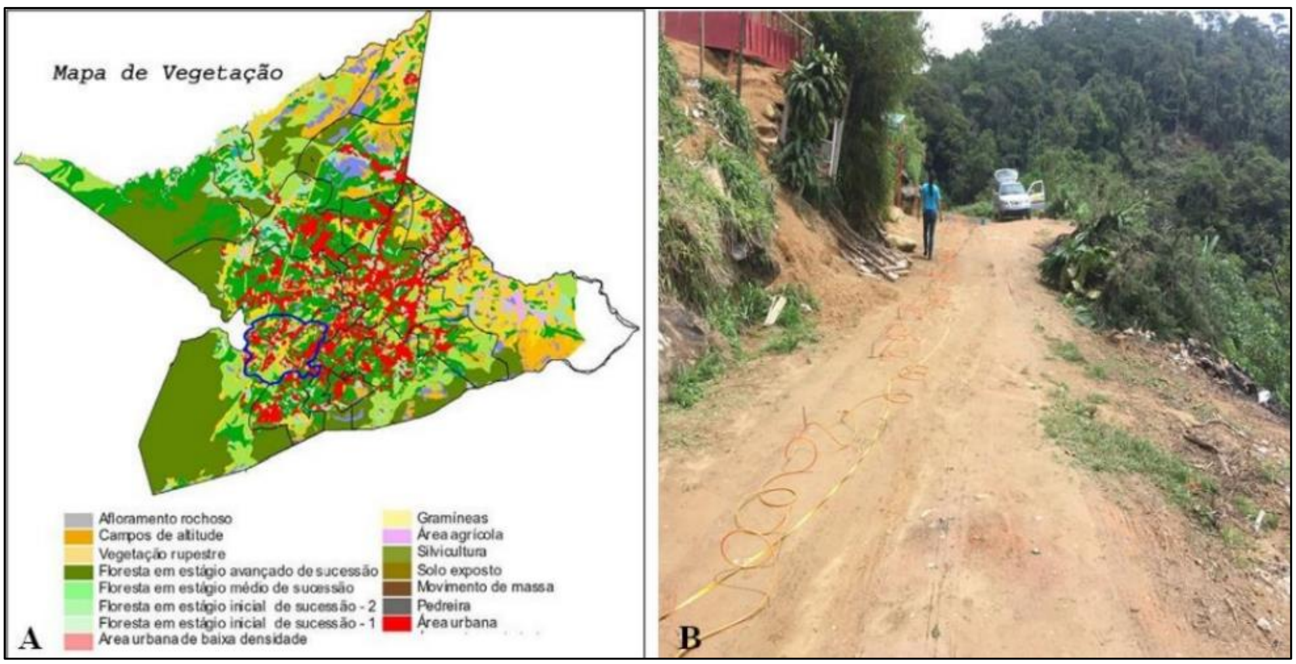

Figure 11 - (A) Vegetation map of the first district with delimitation of the Quitandinha district in green, without scale. Source: adapted from Varanda (2006). (B) Deforestation on Mato Grosso street in Quitandinha.
Source: Authors (2022).

Petrópolis is part of the geomorphological unit of Serra dos Órgãos, with a municipality inserted in the Scarps and Reverses Region of Serra do Mar, formed by a mountainous relief, with a wide variety of escarpments and declivity. The range from 10° to 30° is characteristic of areas with predominance of alluvium and colluvium, between 30° and 45° mostly typical of areas of colluvium and mature residual soils, from 45° and 60° with domain of colluvium areas and residual soils, Varanda (2006), figure 12.

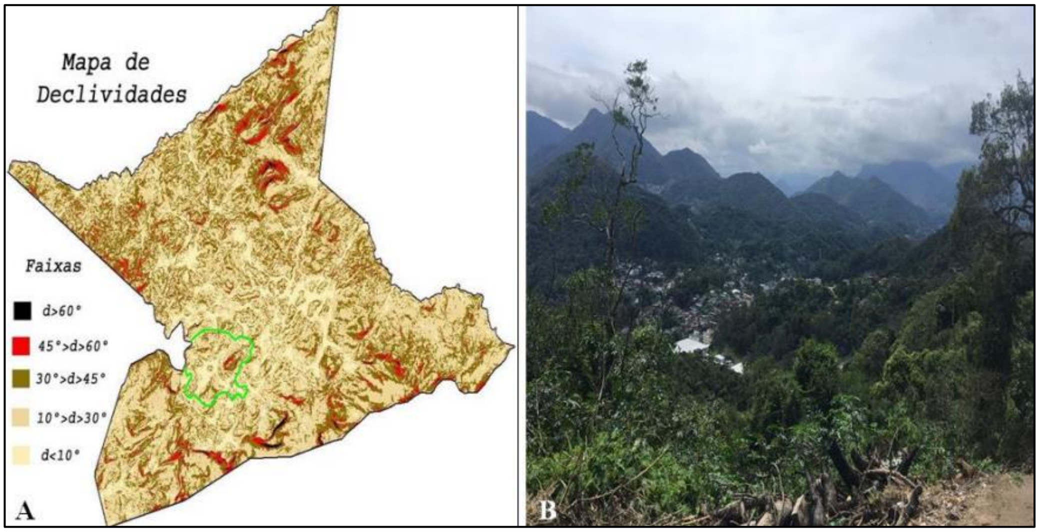

Figure 12 - (A) Declivity map of the first district with delimitation of the Quitandinha neighborhood in green, without scale.
Source: Adapted from Varanda (2006). (B) Relief of Petrópolis through Mato Grosso street.

Serra do Mar is composed of a large part of granites and gneisses, being in the Brazilian Crystalline Complex, Salgado (2013). The municipalities of Petrópolis, Teresópolis and Nova Friburgo, based on Guerra et al. (2007 p.81) are constituted by migmatites and granitoids of Petrópolis with Pre-Cambrian age, extremely fractured and faulted, being, therefore, propitious for the increase of rates of landslides, especially in places of inadequate occupation on slopes. Quaternary sediments are also found in fluvial areas, such as the Piabanha River, figure 13. The Quitandinha neighborhood, located in the first district, is contained in the Petrópolis sheet 1:50,000, with outcrop of rocks from the Rio Negro Unit (Santo Aleixo and Bingen), were mapped by Penha et al. (1979). According to Varanda (2006), the Bingen Unit, consisting of biotite-granitic gneiss, predominates in the area. At the Santo Aleixo Unit, it has transitional contact with the Bingen Unit, being composed of migmatites. Based on Guerra et al. (2007, p. 81), the predominant soils in the region are the red-yellow Latosol and the red-yellow Argisol. However, Cambisols are also found.

Figure 13 - (A) Geological map of the first district, Quitandinha, outlined in green. Source: adapted from Penha et al. 1979 and Souza, 1983). (B) Geological fault in the Quitandinha neighborhood in Petrópolis, in the southern part of the first district.
Source: Varanda (2006).

According to Marques (2006), the Quitandinha neighborhood has few outcrops with sound rock and well-weathered soils, with variations in color and granulometry, where, on technical visits to Mato Grosso Street in Quitandinha , the presence of soils with granulometry ranging from fine to medium sand, silt and clay was observed. Varanda (2006) also carried out a pedogenetic analysis of the soil of the first district (Petópolis) of the Municipality of Petrópolis, noting the presence of shallow soil in Quitandinha, with layers varying between 1 and 2 meters on the outcrops, with soils having blocks varying from centimeters to meters, and may have large amounts of organic matter, figure 14.

Figure 14 - Shallow soil (Neossolo) located in Quitandinha.
Source: Varanda (2006).

With altitudes of 250 m and 1,600 m, the climate is defined as “tropical mesothermal, mild, super humid”, coinciding with the altitude of the municipality of Petrópolis, even though the region is under a predominantly tropical area. However, based on Hack et al. (2003), large temperature variations can occur due to the meeting of the Tropical Atlantic and Polar masses, generating a decrease in rainfall rates and the creation of fog during the winter. In summer, this phenomenon causes heavy rains with thunderstorms, in addition to increased air speed, due to the topographic altitude of the city.

According to Canedo (2011), most of the rainfall in the municipality of Petrópolis is caused by the accumulation of wet masses coming from the Magé plain, carried by the winds to the Petrópolis mountain range, characterized by three different entrances, one from the south in the Palatino river valley , the second through the valley of the rivers Quitandinhas, to the southwest, and the last through the valley of the river Itamarati, to the east, with more rain coming from the Palatino and Quitandinha rivers. Other contributing factors are the high altitude and the proximity of the slope to the sea, which ends up retaining moisture, with the city's annual rainfall varying between 1500 mm and 2600 mm, in the summer with values above 200 mm/month, according to Oliveira et al. (2003)

During the rainier periods, the number of mass movements increases, as the soil undergoes an increase in its mass, in addition to a decrease in its cohesion due to the increase in the degree of saturation. Guidicini and Nieble (1984) indicate that the increase in mass movement indices is caused by the amount of water in the soil, because when infiltrating, the water occupies the voids in the soil, consequently exerting pressure on the grains (poropressure).

4. Mass movements in the study area.

Regarding the intensity of landslide, for Guidicini and Nieble (1984), the mass movements vary based on the type of morphology, geology and geomorphology of the terrain, allied with the anthropic parameters, if they occur in areas that have occurred human intervention, such as irregular or disorderly construction, deforestation, pollution and soil contamination. Regarding the material involved in the mass movement, Hungr et al. (2001) proposes a division based on earth, mud and debris for flow movements.

According to Leroueil et al. (1996), all types of mass movement go through four stages of development, pre-rupture, rupture, post-rupture and the reactivation stage, which occur in sequence. Mass movements can be classified based on kinematics of the movement, type of material that the terrain is made of, and geometry. The kinematics of motion is based on displacement in the mass, as a function of velocity, direction and sequence of displacements. The type of material is defined based on the material that has been displaced, such as soil, rock, debris, among others. The slower the movement of the displacement, the type of movement will be the crawling, it can be the dry or wet material, if it occurs quickly and dry, the type of movement is characteristic the fall.

The velocity of mass movements can be classified and estimated according to the UNESCO International Geotechnical Society (WP/WLI, 1995) and Cruden and Varnes (1996), where the response to the movement varies according to its description. For Hungr et al. (2014), due to the wide variety of possible classifications, the term that each researcher will use in their research and work should be based on what presents the greatest variety of information, thus, avoiding joining more than one type of movement, therefore, each term selected for a specific mass movement must represent the researcher's particular focus, and that, for example; a class defined as complex is useless because almost all mass movements are complex. In the presence of a complex movement, the terminology used should include most of the information without having to mention another type of movement.

Augusto Filho (1994) characterized 53 types of mass movements in four groups based on their characteristics, namely: creeps, slides, flows and falls. The main types of mass movements that affect the regions of Rio de Janeiro are: falling blocks (GEORIO, 2014), tipping (OLIVEIRA, 2004), landslides (AUGUSTO FILHO, 1992; GUIDICINI & NIEBLE, 1984; OLIVEIRA, , 2004), crawling (SILVA, 2006; OLIVEIRA, 2004) and running (SILVA, 2006).

According to Nakazawa and Cerri (1990), because Petrópolis has large slopes in the terrain, the most frequent movements are those of rapid occurrence, such as planar landslides and falling blocks, the most common being landslides, due to the majority of landslides. areas have slopes with a declivity between 10 and 45°. Quitandinha has areas with susceptibility levels ranging from low to high (figure 15), since the slope angle of the terrain can influence the type of mass movement that can occur in the area, thus, slopes with declivity below 10° are less susceptible to mass movement due to the low slope of the terrain, thus being considered as stable slopes (VARANDA, 2006). Slopes between 10 and 30° are more susceptible to creep and slip type mass movements. Between 30 and 60°, slips may occur with higher speeds according to the slope angle. On slopes with declivity greater than 60°, mass movements such as fragment fall are more common due to the high slope (VARANDA, 2006).

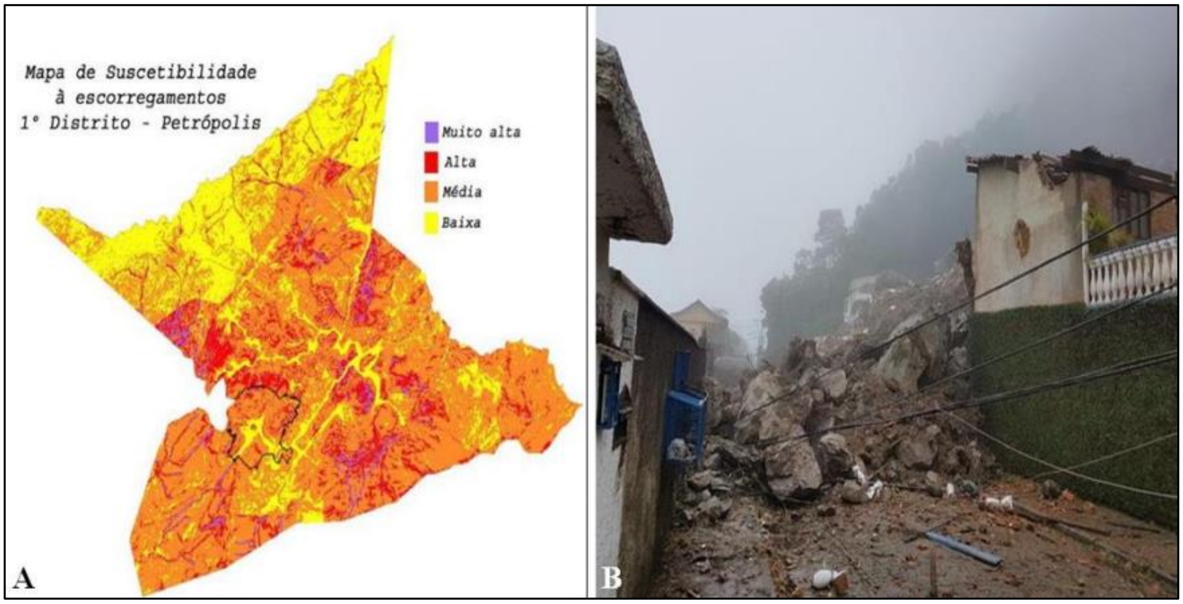

Figure 15 - (A) Landslide susceptibility map. Source: Varanda (2006), adapted by the author. (B): Landslide recorded in the Quitandinha neighborhood in 2017.
Source: G1 (2017) .

In the Quitandinha neighborhood, the most frequent mass movements are crawling and slipping, where in 2017, at Ayrton Sena Ave., caused the destruction of houses. However, fragments may also fall (figure 16A). In 2022, heavy summer rains caused more than 700 landslides throughout the city of Petrópolis, in addition to the flooding of streets leaving more than 238 deaths and hundreds of homeless, with the mass movement of the race type causing the largest number of victims (Figure 16B), as residents did not have time to leave their homes.

Figure 15 - (A) Block falls recorded in the Quitandinha neighborhood in 2017.
Source: G1 (2017). (B) Race on Morro da Oficina (Petrópolis)
Source: Folhapress (2022).

5. Results and interpretations

The contact between the basement and friable soil observed between the depths of 7 m and 13 m, occurred through the acquisition of the electroresistivity section obtained in the field, taking into account the fact that it was not detected in the radargram sections, in depth of up to 7 m. In the contact between the friable soil and the compact soil between the depths of 1 m and 2 m approximately, depths similar to those of the electroresistivity section with the RES2DINV can be observed, being respectively characterized by the resistivity values of 300 ohm.m (water green color) and 500 ohm.m (light blue color). The water saturation simulation points, with resistivity values varying up to 100 ohm.m (dark blue color), indicated water percolations of varying depths, up to 3.5 m, which are also consistent with those of the section obtained with the RES2DINV program. On the other hand, the contact between the compact soil and the basement occurs abruptly with large variations in depth and length, and in the section generated by RES2DINV, the contact is smooth, with few variations in depth. The scattered blocks, indicated by the colors yellow, dark green, and light green, with resistivity values ranging from 300 to 2,000 ohm.m, have similar depth and size with those observed in the section obtained by RES2DINV.

The resistivity cross section generated in the RES2DINV program, after data processing, indicates that a lithological type can have a wide range of resistivity values, based on the resistivity values for unsaturated and saturated sediments and rocks, already known . Thus, in dry soils, located above the water level, the soil resistivity values are considered atypical because they have a wide range of variation (such as 100 to 10,000 ohm.m), which are verified in the section obtained with the RES2DINV program, as the acquisition was carried out at an altitude of 1034m.

In regions 1 and 2 (Figure 9), it is possible to observe areas of low resistivity, indicating saturation zones, which were formed due to the slope and elevation of the terrain. In region 1, a deeper saturation zone with about 3.5 m and 16 m in length, due to the greater proximity to the valley zone, being a point of flow in the area, which could be the valley zone. In region 2, characterized by the accumulation of rainwater, which infiltrates up to about 1.5 m in depth and approximately 10 m in length, which may have been caused by deforestation of the site, increasing the risk of new landslides or remobilization of the soil, as its cohesion has decreased, mainly in region 1, where water percolation occurs more intense.

The contact between friable soil and compact soil occurs between 1 and 2.5 meters deep in most of the radargram section (Figures 4 and 6), defined by the color change between dark blue and light blue, which can be observed in the two GPR sections, at approximately the same depth, with the deepest contact being in area 1, due to the presence of water drainage, being between 2 and 3 m deep. At point 3, it is possible to observe an area of compact soil, which delimits the areas where saturations occur in areas 1 and 2, indicated by the difference in color from light blue to water green, and it is also possible to observe the variation in depth between the layers of compact and friable soil, as in the GPR sections of lines 1 and 2. At point 4, there are basement rocks, due to the high resistivity values, above 5,000 ohm.m (dark wine color), which are located at a depth of more than 4.5 m and an extension of approximately 30 m. At points 5 and 6, they can be characterized by blocks of different sizes, spread across the area with resistivity ranging between 2,500 ohm.m and 3,000 ohm.m (brown color), at a depth greater than 3m, being also found in line 2 of the section of GPR.

The use of the GPR method proved to be more effective in relation to electroresistivity to identify the exact location and size of the blocks spread across the study area. However, through the electroresistivity method, it was possible to obtain the places where water saturation occurs, and the identification of the presence of blocks scattered throughout the place. Therefore, for a more detailed study of slope stability, the use of the two geophysical methods is recommended, as they are complementary and effective for the environmental study.

6. Final considerations

The correlation of the geophysical methods of GPR and Electroresistivity allied with the study of regional and local geology proved to be a good strategy for the verification of typical mass movements in the study area, as well as the stability of the slope. Through the analysis of geophysical data combined with studies on landslides in the area, it is possible to conclude that the slope presents an average risk of landslide, due to the occurrence of points with more than 8 m in length with water saturation in the soil at depths greater than 1 m, where the contact between compact and friable soil is found. Aggravated by the intensification of deforestation of the site for the construction of houses and irregular land use, such as: concentration of garbage, rubble, and remobilization of the soil, indicating that a mass movement can occur at any time in the studied area, requiring a more detailed and urgent study to remedy and control the soil situation at the site.

An alternative to minimize the risks of landslides is to carry out geophysical mapping of GPR and ERT throughout Mato Grosso Street, to identify all areas with passage of drainage, buried blocks and infiltration zones, thus detecting the places with a greater probability of landslide, so that high-risk areas are determined, making it possible to prepare evacuation plans, as well as the creation and application of techniques to minimize soil movement. Therefore, the presence of several blocks spread over the layers of the GPR and Electroresistivity sections, indicates that several mass movements have already occurred in Mato Grosso Street, being them of medium to high energy due to the size of the transported blocks.

There is also a need for more intense supervision regarding the construction of housing, due to the growing irregular construction in the place, which generates deforestation of the forest that contributes to the destabilization of the slope, as well as the increase in the amount of garbage scattered on the street and lack of basic sanitation. , where sewage from houses is thrown directly into the street, without any type of treatment, as a result, when it infiltrates into the soil, it generates disaggregation of soil components.

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