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Mass movements identification in urban expansion areas: poços de caldas case study, minas gerais, Brazil

Abstract

Natural disasters in the last few decades have killed several million people besides having caused financial losses and social impacts. Also, the accelerated urbanization process in recent decades worldwide has led to the cities growth, often in inappropriate areas for occupation, increasing danger and risk situations related to natural disasters. Our work identified mass movements in an urban expansion area in the Poços de Caldas municipality and evaluated the characteristics of different physical environment units and their interaction with this type of building work. Three areas with potential risks to mass movements were identified: the area that includes points P1, P2, P3 and P4, which is dangerous for the construction of residences, automobiles and passers-by; other that includes points P5, P6 and P7, in which much of its area should be of permanent preservation and could not be occupied; and the area that includes Point P8 (constructed landfill), which presents heterogeneous materials, a slope and a large number of voids in the soil that can lead to the lost of load and lift capacity, therefore to serious accidents. For the three areas, it is recommended to conduct in-depth studies that include mass movements risk areas survey and the formulation of guidelines for measures and restrain works, in order to prevent instability processes aimed at future safe engineering works. Thus, it is suggested that the municipality review the Master Plan and its areas of urban expansion, allowing the implementation of preventive measures, which reduces the possibility of potential economic losses and human lives. In addition, it is suggested the creation of a monitoring plan to coexist with situations of mass movements risk, at relatively safe levels for the population that will occupy this area of urban expansion, located in Poços de Caldas, State of Minas Gerais, Brazil.

Keywords: natural disasters, surface dynamics, geotechnical profiles, soil, landfill, environmental planning, environmental management

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Introduction

Natural disasters in the last few decades have killed several million people, with an annual global loss of about 150,000 people. Financial losses resulting from natural disasters already exceed $50 billion a year and do not include social impacts such as job loss, mental anguish and reduced productivity.[1] In addition to the intensity of natural phenomena, the accelerated urbanization process in recent decades worldwide, including Brazil, has led to the cities growth, often in inappropriate areas for occupation, increasing danger and risk situations related to natural disasters.[2] In Brazil, 493 natural disasters were officially reported, causing 183 deaths and affecting 18.5 million people.[3] The main phenomena related to natural disasters in Brazil are derived from the Earth's external dynamics, such as floods and spates, landslides and / or rockslides and storms. These phenomena usually occur associated with intense and prolonged rainfall events in the rainfall periods which corresponds to summer in the south and southeast regions and winter in the northeast region.[4] The present work aims the identification of mass movements in an urban expansion area in the Poços de Caldas municipality (Minas Gerais State), by evaluating the characteristics of the different physical environment units and their interaction with this type of building work. This analysis can be used as an important instrument for environmental planning and management in urban expansion areas.

Materials and methods

Fieldworks were carried out in order to recognize the study area, make a photographic survey, take coordinates and describe the relations with the original rocks and the genesis of the superficial soil, along with the identification of the superficial dynamics processes existence and/or potentiality of the existence in the urban expansion area. Afterwards, a description of the relation between the original rock and the genesis of the superficial soil (saprolite, lateritic, etc.) was carried out, identifying the existence and / or potentiality of the existence of surface dynamics processes in the study area. The vegetation, anthropic interferences and geotechnical indicators were observed according to Tables 1 & Table 2, which present all the documentation of susceptibility to the surface dynamics processes of the analyzed section.

Table 1 Applied field questionnaire for the analysis of the geological-geotechnical profiles. Modified:[5]

Profile: Date:	
Coordinates:	
Altitude:	
Outcrop type:	( )quarry ( ) mine ( ) road/ railroad ( ) waterfall ( ) river bed( ) wall ( ) gully ( ) flagstone / crest ( )

Table Continued

Profile: Date:	
Lithology:	( )sandstone ( ) claystone ( ) conglomerate ( ) basalt ( ) diabase ( ) diamictite ( ) shale ( ) siltstone ( ) turbidite ( ) granite ( ) gneiss ( ) quartzite ( ) other________________
Composition:	( )quartzose ( ) feldspatic ( ) micaceous ( ) other___________
Structure class:	( )foliation ( ) lineation ( ) fault ( ) bedding ( ) fracture ( ) rib ( ) fold ( ) joint
Structure:	( )bedding ( ) lamination ( ) plane ( ) cross ( ) graded
Parental material:	( ) rock ( ) weathered rock ( ) intensely weathered
Regional relief:	( )plain ( ) soft wavy ( ) wavy ( ) strongly wavy ( )mountainous ( ) steep
Situation and land slope:	( )plain ( ) slightly sloping ( ) inclined
Local relief–topographic position:	( ) bottom ( ) medium portion ( ) upper
Local relief–inclination features:	( ) fall face ( ) convex ( ) concave ( ) straight segment
Stoniness:	( ) non stony ( ) lightly stony( ) medium stony ( ) stony ( )highly stony( ) extremely stony
Rockiness:	( ) not rocky( ) lightly rocky ( ) medium rocky ( ) rocky ( )highly rocky ( ) extremely rocky
Surface dynamics:	( )absent ( ) laminar ( ) furrows ( ) ravines ( ) gullies( )landslide ( ) block fall ( ) creeping ( ) silting( )other: _________________
Watershed:	( )high proximity to water bodies ( ) springs ( ) recharge area ( )damming ( ) larger infiltration ( ) larger runoff( )other: _________________
Drainage:	( )excessively drained () strongly drained ( ) markedly drained ( ) well drained () moderately drained () imperfectly drained () poorly drained () very poorly drained
Vegetation:	( ) absent vegetation ( ) low vegetation ( ) shrub vegetation ( )treevegetation
Vegetation type:	( ) equatorial ( ) tropical ( ) sub tropical ( ) restinga ( ) cerrado ( ) caatinga ( ) rural ( ) other: _________________
Roots:	( )many ( ) common ( ) few ( ) rare
Biological factors:	( )worm ( ) termite ( ) ant ( ) armadillo
Climate:	( ) equatorial ( ) tropical ( ) temperate ( ) other: _________________
Anthropic interferences:	( )highway ( ) residence ( ) urban agglomeration ( ) enterprise( ) plantation ( ) tourist attraction ( ) works( )other: _________________

Table 2 Field questionnaire applied in this study for the analysis of pedological horizons in geological-geotechnical profiles. Modified:6,7

Main horizons:	( ) O ( ) H ( ) A ( ) E ( ) B ( ) C ( ) R
Transitional horizons:	
Intermediate horizons:	
Transition between horizons:	( ) abrupt< 2,5 ( ) clear 2,5-7,5 ( ) gradual 7,5-12,5 ( ) diffuse> 12,5
Topography between horizons:	( ) Flat and horizontal ( ) undulate or sinuous ( ) irregular( )broken or discontinued
Depth:	
Thickness:	
Color:	( )dark ( ) clear ( ) red ( ) gray ( ) yellow ( )mottled
Mottling:	( )few 2% ( ) common 2 a 20% ( ) abundant> 20%
Mottling size:	( )small< 5 mm ( ) larger 5 a 15mm ( ) big> 15mm
Particle size and texture:	( )sand: rough, non plastic and non sticky ( ) silt: silky, plastic and non sticky ( ) clay: silty, plastic and sticky

Table Continued

Structure:	( )aggregation absence/ simple grains ( ) aggregation absence/ massive ( ) prismatic with faces and edges ( ) columnar with rounded superior face ( ) angular and sub angular blocks ( ) laminar horizontal ( ) granular
Consistency:	( )wet: plasticity and stickiness ( ) wet: friability, friable, firm or very firm ( ) dry: hardness or toughness, loose, soft, hard or very hard
Alteration profile in engineering geology:	( )organic I ( ) lateritic II ( ) saprolitic soil III( )saprolite IV ( ) heavily altered rock V ( ) altered rocks VI ( ) non altered rock VII
Pedological classification in geotechnics:	( )Class S1,EluvialSoil( ) Class S2, Alteration Soil ( ) Class R3, Soft Altered Rock ( ) Class R2, Hard Altered Rock ( ) Class R1, Non Altered Rock
Pedological classification according to digging degree:	() 1. Crude and fluent, sands, organic soils and peat () 2. Mild material, clayey and sandy soils ( ) 3. Mild rock, more or less rigid with degrees of change () 4. Hard rock, little or non altered ( ) 5.Very Hard Rock, non altered to slightly altered
OTHER ASPECTS:	SCHEMATIC PROFILE
Cutans( )	
Nodule( )	
Laterite( )	
Gravels( )	
Concretion( )	
Charcoal( )	
Roots ( )	

Results and discussion

The study area is located in the municipality of Poços de Caldas, Minas Gerais State, Brazil (Figure 1). The Europe Avenue is an important connecting route between the affluent neighborhoods of the city and was designed to meet the need of trade that residential neighborhoods need. Currently, the area has wide sidewalks, few trees, a river, some allotments and a kindergarten school, located on an artificial landfill, built to house local businesses. The urban expansion area geomorphological context comprises hills reliefs with rounded tops, showing well-developed alteration profiles. The predominant lithology is tinguaite alkaline rock and occurs in the study area within grayish outcrops, with amygdales and venules in some samples. This lithology gradesto a soil of gray-purple coloration and limonitized spots of orange color.

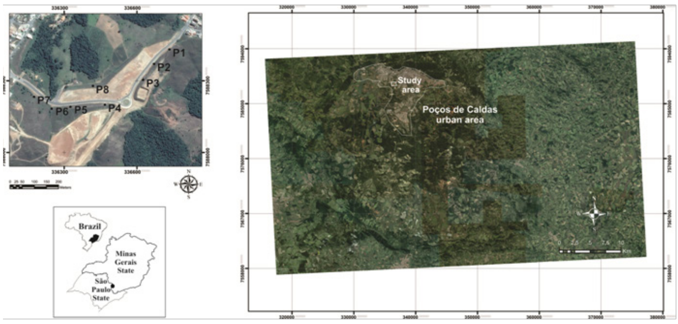

Figure 1 Location of the sampling points where the identification of mass movements was made, within the urban area and study area in Poços de Caldas, Minas Gerais, and Brazil.

Point P1 located at coordinates 21°48.05'S and 46°34,809'W at an altitude of 1339m corresponds to geological areas where the tinguaitessubstrate are highly weathered. Regarding the surface processes, it is possible to notice the existence of blocks fall, probably originated by faults that have horizontal and sub horizontal structures to the reference plane, besides being located in a water divider and therefore a strongly drained place. The relief has a convex slope and the soil profile features a saprolite soil horizon and saprolitic horizon. In the saprolite soil horizon, we observed gravel, residual soil with the source rock structures and few blocks. In the saprolitic horizon, the transition between the soil mass and the rock mass is well marked and blocks of rock with several stages of alteration and spheroidal exfoliation are present (Figure 2) (Table 3).

Point P2 is located at the coordinates 21°48.072' S and 46°34.827'W at an altitude of 1342m and according to the geological process, it was noted the existence of blocks fall, as described in P1. The relief presents a convex slope and the soil profile presents a rough, non-plastic and non-sticky texture and is composed of a much altered rock horizon, saprolitic horizon and saprolite soil horizon. In the much altered rock horizon, the observed rocks are in an advanced alteration stage, lacking luster and with little resistance. This point present planar gliding features (Figure 2) (Table 3). Point P3 located at the coordinates 21°48,125' S and 46°34,849'W at an altitude of 1338m does not present block fall or occurrence of another geological process of the surface dynamics, and its relief presents a rectilinear slope. The soil profile presents a silky, plastic and non-sticky texture and differs from P1 and P2 by presenting a saprolite soil horizon with few blocks/rock fragments (Figure 2) (Table 3).

Point P4, which is located at coordinates 21°48.072' S and 46°34.827'W at an altitude of 1342m, presents blocks fall along with a convex slope. The soil profile presents a rough, non-plastic and non-sticky texture and is composed of a much altered rock horizon in an advanced alteration stage, lacking luster and with lower resistance when compared to the rocks observed in the altered rock horizon (Figure 2) (Table 3).

Point P5 located at coordinates 21°48,139'S and 46°35,004'W and altitude of 1322m, corresponds to areas with lateritic soils and highly weathered tinguaites. This point does not show blocks fall or occurrence of another geological process and its relief presents a rectilinear slope. The soil presents a rough, non-plastic and non-sticky texture and is composed of the organic and lateritic horizons, saprolitesoil and saprolitic horizons. In the organic horizon there is a great amount of leaves and decomposing organic material. In the lateritic horizon, a roughness variation of the analyzed particles is observed by tactile sensation and a predominantly prismatic structure formation. In the bottom horizons, the same characteristics presented in the other analyzed points were observed, saprolite horizons with altered blocks of rock (Figure 2) (Table 3).

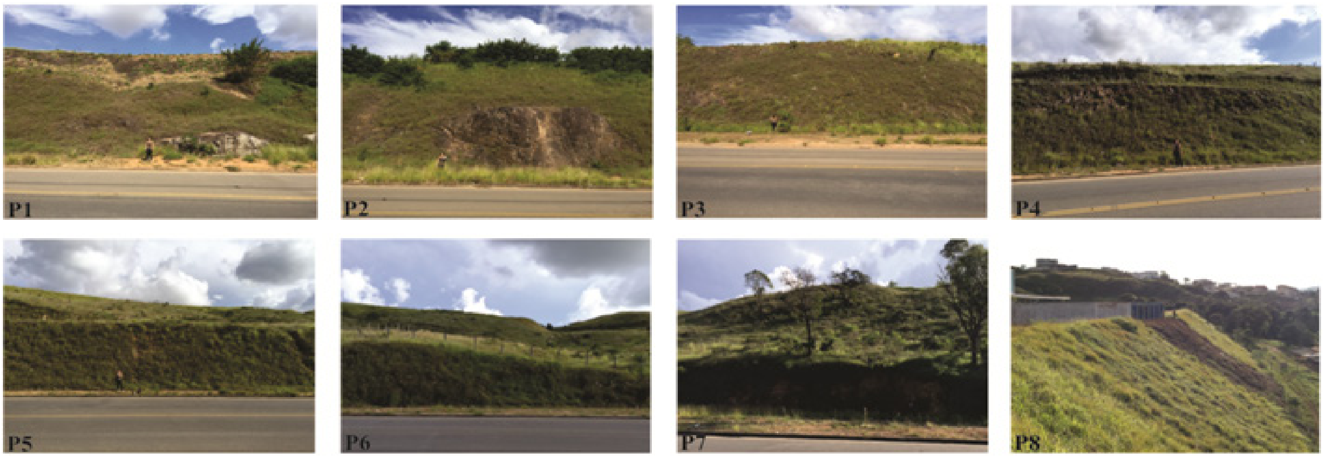

Figure 2 Sampling points (P1, P2, P3, P4, P5, P6, P7 e P8) analyzed for mass movements.

Table3 Results of the physiographic characteristics analyzed in the field

Point	Geology	Slope profile	Soil profile	Drainage density	Geological processes	Vegetation and land use
1	Tinguaite	Convex	Saprolite soil horizon and saprolitic horizon	Heavily drained	Blocks fall	Underbrush
2	Tinguaite	Convex	Saprolite soil horizon, saprolitic horizon and very altered rock horizon	Well drained	Blocks fall and planar gliding	Underbrush and shrubby
3	Tinguaite	Rectilinear	Saprolite soil horizon	Moderately drained	Absent	Underbrush
4	Tinguaite	Convex	Very altered rock horizon and altered rock horizon	Moderately drained	Blocks fall	Underbrush
5	Tinguaite	Rectilinear	Organic soil horizon, lateritic horizon, saprolite soil horizon and saprolitic horizon	Well drained	Absent	Underbrush
6	Tinguaite	Concave	Lateritic horizon	Excessively drained	Absent	Underbrush
7	Tinguaite	Rectilinear	Organic and saprolitic horizons	Well drained	Rock fragments	Underbrush
8	Tinguaite	Rectilinear	Heterogeneous horizon	Well drained	Grooves, sliding and blocks fall	Absent

The Point P6 at coordinates 21°48,141' S and 46°35,040'W and an altitude of 1329m is near a slope where there is a spring, which drains its waters below the Avenue. It is a place with a concave slope relief, typical of washing/draining water areas. The main geological processes observed at this point were the several fractures formed mainly at the bottom of the slope, where there is the main drainage. The site has little variation in the alteration profile, with a lateritic colluvionar cover of approximately four meters, digging degree of two, which can be excavated with ease. The soil profile presents silky, plastic and sticky texture, prismatic structure and, like Point P5, is composed of a lateritic horizon with grains of prismatic structure (Figure 2) (Table 3). Point P7 is located after the river spring of the Point P6, at coordinates 21°48.55'S and 46°35.036'W and altitude of 1345m, on a concave to rectilinear slope with good drainage. As to the surface dynamics it is possible to notice the existence of few weathered rocks fragments (Figure 2) (Table 3). The soil presents silky, plastic and sticky texture and is composed of anorganic soil horizon and a saprolitic horizon, which grades to a lateritic on

e. In the organic soil horizon, as in Point P5, it is observed a great amount of organic matter and lumpy structure. Just below, there is a saprolite horizon that grade to a lateritic horizon, with prismatic structure grains and small spots (mottling). Point P8 is located at coordinates 21°48.00'S and 46°34.057'W at an altitude of 1342m, in a constructed landfill (Figure 2) (Table 3). The area presents a variety of surface material, bricks, woods and wastes, heterogeneous composition, and it is not possible to distinguish horizons. The main geological processes are soil sliding in the landfill slopes, and it is possible to record some erosive features in the form of grooves. This point presents a digging degree equal to 1, quite unstable and sliding features close to a construction. The results indicate several characteristics for the observed points and although the points present the same lithology, these have different alteration stages. In addition, some points are also differentiated by the relief drainage and type of material, such as the constructed landfill (Table 4).

Table 4 Characteristics of the sampling points (P1, P2, P3, P4, P5, P6, P7 e P8) observed in the field

Point	Color	Consistency	Texture	Mottling	Digging Degree
P1	Yellow	Dry	Sand	Absent	Soft rock
P2	Red	Dry	Sand	Absent	Soft rock
P3	Red	Wet	Silt	Absent	Soft rock
P4	Red	Wet	Silt	Absent	Soft rock
P5	Dark red	Humid	Silt	Absent	Soft rock
P6	Dark red	Wet	Clay	Absent	Soft material
P7	Light red	Wet	Clay	Little quantity	Soft material
P8	Yellow/ Ochre	Dry	Silt	Absent	Friable and fluent

The area that includes points P1, P2, P3 and P4 features a rocky substrate, marked slope and several geological processes. The digging degree equal to three makes it difficult to move earth on the surface and consequently engineering works. The rocks disintegration and blocks fall occurrence makes the area dangerous for the construction of residences, automobiles and passers-by. Points P5, P6 and P7 encompass an area that have particular characteristics that make it difficult to occupy without due technical care, as well as places that are not suitable for engineering works. Part of the area is located in the bottom portion of a slope with the intense presence of a drainage system. Moreover, much of its area should be of permanent preservation and could not be occupied. The occurrence of large rainfall events can overwhelm the drainage system present at the site and cause structural damage in the future. Preventive erosion works is recommended in this area, such as the construction of terraces and rainwater drainage systems. The area that includes Point P8 (constructed landfill) presents heterogeneous materials and a slope, which makes the constructive design of engineering works with foundations complex, so the type of work, loads, admissible settlements, characteristics of the rubble and the soil found below it must be taken into account. The topography of the region and the existence of other interferences to determine the type of foundation suitable for the site should be mandatory items for future engineering works. In large rainfall events, because of the large number of voids in the soil (heterogeneous materials), this area can lose its load and lift capacity, which can lead to serious accidents. A detailed evaluation of the materials geotechnical behavior and depth of the groundwater level is recommended. For the three areas previously mentioned, it is recommended to conduct in-depth studies that include mass movements risk areas survey and the formulation of guidelines for measures and restrain works, in order to prevent instability processes aimed at future safe engineering works.

Conclusion

The identification of areas with potential risks to mass movements should encourage structural actions, technical preparation of municipal employees, modernization of public attitudes laws and preparation and/or awareness of the population. Thus, it is suggested that the municipality review the Master Plan and its areas of urban expansion, allowing the implementation of preventive measures, which reduces the possibility of potential economic losses and human lives. In addition, it is suggested the creation of a monitoring plan to coexist with situations of mass movement's risk, at relatively safe levels for the population that will occupy this area of urban expansion, located in Poços de Caldas, State of Minas Gerais, Brazil.

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Conflict of interest

The author declares that there is no conflict of interest.

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