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SURVEY AND TEMPORAL AND EVOLUTIONARY ANALYSIS OF LINEAR WATER EROSION ON A SAMPLE HILLSLOPE OF THE LEOPOLDO RIVER

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ABSTRACT

The article presents a temporal and evolutionary analysis of linear water erosion, as from a survey of a sample hillslope of the Leopoldo river, located in the municipality of Agudos (SP). The survey was elaborated from satellite images made available by Google Earth, which allowed to identify the main characteristics of erosive features. The analyzed characteristics are: slope position, length, width, line of inclination, shape, evolutionary stage, incision system, possible origin, curvature longitudinal and transversal. So, the article made it possible to study the erosions' behavior and the relationship with local morphology.

KEYWORDS: soil erosion, gully, hillslope.

LEVANTAMENTO E ANÁLISE TEMPORAL E EVOLUTIVA DAS EROSÕES HÍDRICAS LINEARES EM UMA ENCOSTA AMOSTRAL DO CÓRREGO DO LEOPOLDO

RESUMO

O artigo apresenta uma análise temporal e evolutiva de erosões lineares hídricas, a partir de um levantamento de uma encosta amostral do córrego do Leopoldo, localizado no munícipio de Agudos (SP). O levantamento foi elaborado a partir de imagens de satélite disponibilizadas pelo Google Earth que permitiram identificar as principais características das feições erosivas. Entre as características analisadas estão: posição na vertente, comprimento, largura, linha de inclinação, forma, estado de evolução, possível origem, curvaturas longitudinal e transversal. Desse modo, o artigo possibilitou a realização de um estudo sobre o comportamento das erosões no local e a relação com a morfologia local.

Palavras chave: erosão do solo, voçoroca, encosta.

1 INTRODUCTION

The growth in population from the beginning of the second half of the 20th century has demanded a greater production of food to supply urban centers. A consequence of this acceleration in production has been an intensification of land use in rural areas, where agricultural workers often lack adequate production techniques and, as a result, have generated environmental problems, such as river silting, resulting in unproductive land with unusable soil. Such problems have been exacerbated by the growing number of agricultural units that adopt poor husbandry techniques, in terms of soil correction and maintenance (BERTONI & LOMBARDI NETO, 2014; LINHARES *et al.*, 2014). A specific consequence of this inadequate land use is the removal of the vegetation that serves as a natural defense and protects soils against the dispersion of water (BERTONI & LOMBARDI NETO, 2014). Vegetation clearance has given rise to large areas where the impact of raindrops loosens soil particles, which are then carried away by surface runoff, initiating the erosion process (BERTONI & LOMBARDI NETO, 2014). Surface runoff can occur in a laminar form, when the diffuse flow becomes turbulent and erodes the soil surface, or linear, when the flow develops in a concentrated manner and along thalweg lines. This flow concentration leads to the gradual appearance of linear erosion features, such as rills, gullies and ravines. Rills are the first sign of erosion that then evolve into gullying, characterized by erosion at greater depths is. When erosion develops along a water table, the combined action of surface and subsurface water leads to the initiation of the gullying process.

It is known that the effects of gullying and/or ravinement may be irreversible if there is no intervention and/or the application of preventative agricultural techniques, such as soil maintenance or correction. In 1989, it was estimated that 80% of cultivated land in the State of São Paulo was subject to erosive processes, due to a lack of effective maintenance/correction in agricultural areas; that is, beyond the limits of natural soil recovery (DAEE/IPT, 1989). In 1992, more than 10,000 significant linear erosions (with dimensions greater than 3m in depth and 10m in width) were recorded in the State. Furthermore, 70% of the linear erosions recorded were located in the Western Plateau Geomorphological Province, one associated with the Bauru Group, which occupies approximately 40% of the total area of the State (SALOMÃO, 1992). In 2010 and 2011, using Google Earth and IBGE topographic maps, the Registration of Erosion Points in the State of São Paulo project, in conjunction with DAEE, registered 39,864 erosion processes in rural areas across 593 municipalities. Of the total number of registered processes, 30,004 were classified as gullies and 9,860 as ravines (ALMEIDA FILHO, 2015). In URGHI-16 alone - an area encompassing the Batalha River basin and part of the Tietê River basin - 538 urban linear erosions were registered (528 gullies and 10 ravines). The predominance of gullies is demonstrative of the inadequate soil management practices and environmental imbalance found in rural areas across the State of São Paulo (IPT, 2012).

According to the State erosion map, the region of Bauru and Agudos has a high predisposition to erosion, being particularly susceptible to the phenomenon of piping – a condition in which the formation of gullies is highly likely (KERTZMAN, 1995). It is notable that 65%

of the URGHI-16 land use classification is anthropogenic field/pasture (IPT, 2012). In the municipality of Agudos, where the source of the Batalha River is located, the existence of critical erosion problems and their respective characteristics was highlighted in mapping carried out by DAEE (Department of Water and Electric Energy) and IPT (Institute of Technological Research of the State of São Paulo) in the years 1986, 1988, 1990 and 1992.

Based on the history of erosive phenomena occurrence and dense anthropic activity, a hillslope within the Leopoldo River basin, the source region of the Batalha River in the Jacutinga Hills, was earmarked for study (Figure 1).

Thus, the objective of the work presented here was to carry out a temporal and evolutionary survey of the characteristics of linear water erosion, on a hillslope of the Leopoldo River basin, in the municipality of Agudos/SP, through systematization, to contribute, as a control sample, to future geomorphological flow concentration analysis.

2 LOCALIZATION AND CHARACTER OF THE STUDY AREA

The municipality of Agudos is located between the parallels 22°24' and 22°30' South and the meridians 49°00' and 49°06' West, in the Central-West area of the State of São Paulo, in the Paulista West Plateau. The hillslope studied is found in the Leopoldo River basin and forms part of research on linear rainfall erosion in the Jacutinga Hills (Figure 1). The area of delimitation is at an average altitude of 640m, with the Leopoldo River as its main tributary, and has been classified in the APA of the Batalha River as an Attribute Protection Zone (ZPA) (MACARI, 2019).

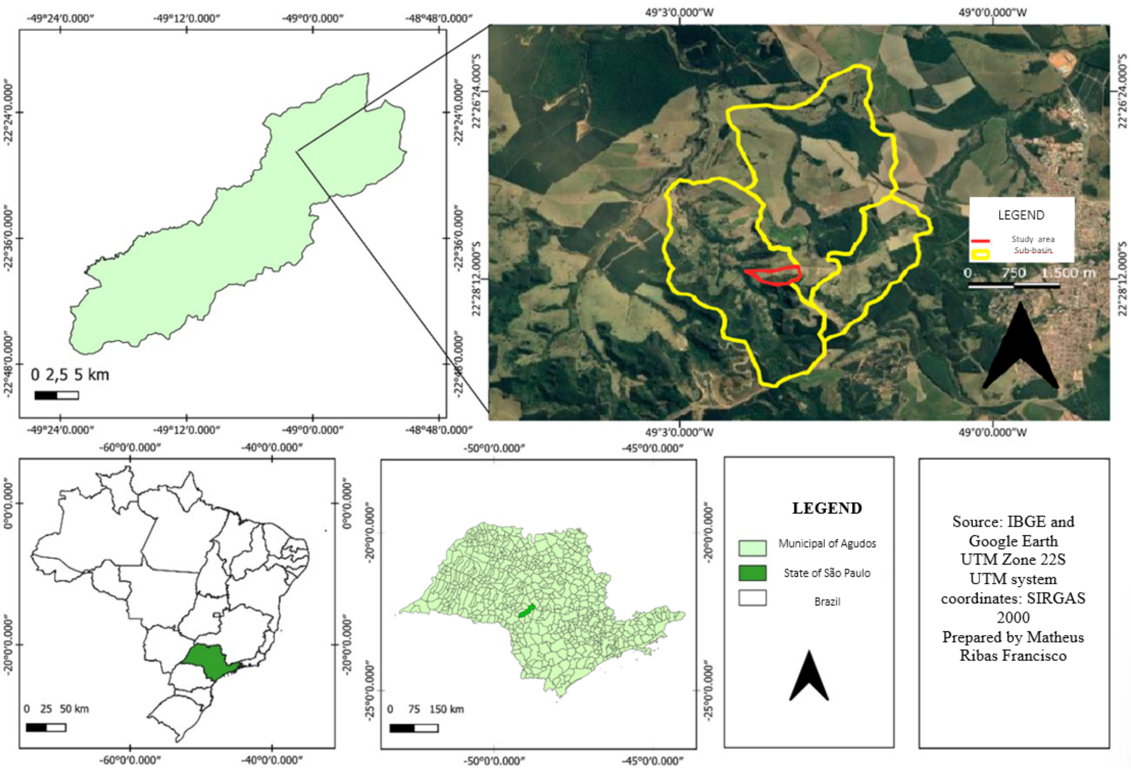

Figure 1: Location of the study area in Jacutinga Hills, municipality of Agudos (SP – Brazil), in which the delimitation of the hillslope considered is highlighted.

In relief, the hillslope of the Jacutinga Hills is marked as a transition characterized by non-scarp hillslopes, with medium declivity (15% to 30%) and amplitudes greater than 100 m. These hillslopes are furrowed by subparallel valleys, being broken up into linear interfluves with angular and rounded tops with hillslopes having straight profiles. The drainage, therefore, is of medium density, with a pattern of closed valleys (KOFFLER, 2000). Near the town of Agudos there are elongated uplands and spiers, which have angular to flattened tops and ravine slopes with straight profiles, but occurring in smaller quantities. Notably, Salomão (1994), when studying the Middle Hills of the Bauru Plateau (SP), defined them as slopes of between 10% to 20% and less than 500 meters of ramp.

The local pedological characteristics are defined as of thin and conglomeratic poorly selected sandstones, with a presence of carbonate horizontals. Thus, the pedological class is Red Yellow Podzolic with a sandy/medium texture (SALOMÃO, 1994). This type of Red Yellow Podzolic soil with sandy/medium texture, except for the basic and fine sedimentary rocks, is of mixed origin. It occurs in smooth and more wavy reliefs. It has a less cohesive surface and the subsurface horizontals are less permeable, therefore making it highly susceptible to erosion. It is of average fertility, due to the carbonate contribution found in the west of the State of Sao Paulo (EMBRAPA, 2018). Sandy soils are those most susceptible to erosion. Setzer (1949), in a classification of soils in the State of São Paulo, highlights the groups with deep sandy characteristics (permeable, acidic and with poor chemical and organic matter elements) as the most susceptible to erosion processes.

3 SYSTEMATIZATION FOR CLASSIFYING EROSIONS

Erosive phenomena can be classified in relation to shape, location on the slope, dimensions, and drainage characteristics, among others. Oliveira and Francisco (2022) formulated a systematization model based on selected bibliography, which was used for the qualitative classification of linear erosion features in the study area of the present research. Thus, in addition to the aforementioned characteristics, the evolutionary stage, incision system, possible origin, influencing factors and horizontal and vertical curvatures of the slope were considered (Table 1).

Slope position	Middle		Top		Bottom	
Length	Long		Medium		Short	
Width	Wide		Medium		Narrow	
Line of inclination	Transversal			Longitudinal		
Basic shape	Smooth Ovoid		Lobulated Ovoid		Coalescent Ovoid	
	Smooth Periform		Orthogonal		Linear	
	Others					
Evolutionary Stage	Stabilized		In Development		Corrected	
Incision System	Connected		Disconnected		Integrated	
Possible Origin Influencing factors						
Curvature - (longitudinal / transversal)						

Table 1: Model of the systematization formula, modified from Oliveira & Francisco (2022).

In order to characterize and analyze the evolution of erosion, a sample hillslope was selected within the Leopoldo River basin, and divided into three areas, following proximity criteria and similar characteristics of the linear erosion features in each area (**Erro! Fonte de referência não encontrada.**).

The hillslope, divided into Area 1, Area 2 and Area 3, taking into account the temporal evolutionary process of its features, was studied based on the observation of satellite images from Google Earth from the years 2010, 2013, 2015, 2016, 2018 and 2021. In addition, Using Google Earth tools, the principal measurements of the features analyzed were estimated.

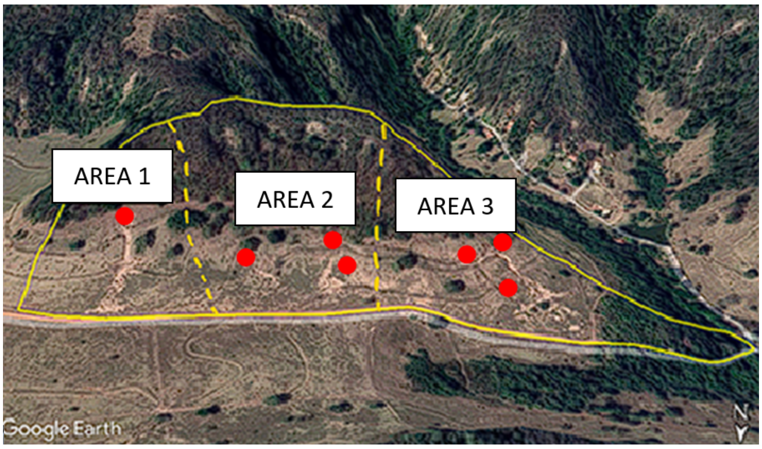

Figure 2: Subdivision of the hillsope into three areas, showing the locations of the places where the features analyzed occur.

The evolution of erosion measurements was analyzed using Google Earth images, and the dimensions classified as either small, medium or large, following the parameters established by Furlani (1980) (Table 2).

Measurements	Large	Medium	Small
Length	≥ 500m	≤ 500m	100m
Width	≥ 50m	≤ 50m	10m

Table 2: Gully Dimensions.

The features were also classified in relation to the lines of greatest slope, which could be transverse (perpendicular to the line of greatest slope) or longitudinal (adjusted to the line of greatest slope). In addition, basic shapes were classified as: a) smooth ovoid or pear-shaped; b) lobed ovoid; c) coalescent ovoid; d) linear; e) orthogonal; and f) curvilinear (**Erro! Fonte de referência não encontrada.** and Figure 2). A Further classification used considered the position in relation to the elevation level at which the erosion occurs: a) low slope; b) medium slope; c) high slope (FURLANI, 1980).

Forms	Description
Smooth ovoid or pear-shaped	Associated with a single hydrographic, it is a classic shape - disregarding the scallops present at the borders. It functions as a reception basin and a drainage channel.
Lobulated ovoid	In the borders, there are several cuts that evolve obliquely or perpendicular to the channel.
Coalescent ovoid	Junction of two or more scalloped or smooth erosive shapes.
Linear	The body of the shape elongates in such a way that it assumes a straight-line configuration.
Orthogonal	Involving two straight branches which intersect again.
Curved	Displays the erosion feature as curves.
Composite	Combination or evolution of other (varied) forms.

Table 3: Shapes of the erosive features, adapted from Furlani (1980).

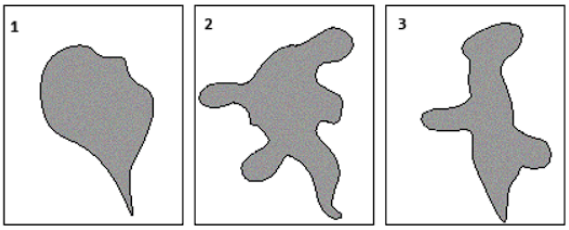

Figure 2: Basic shapes: (1) ovoid, (2) coalescent, and (3) linear.

The analysis of the evolution of the linear erosion features studied considered their condition of stability or development. In addition to analyzing the dimensions during the period of study, the existence of vegetation within each feature under consideration would act as an indication of stability (MERCALDI & FUREGATTI, 2020), while the increase in sedimentation at banks of erosion demonstrate the intensification of development. Other influencing factors on the occurrence of features, such as paths, construction of contour lines and removal of the vegetation layer were also analyzed (CHEROBIN, 2012).

Another classification considered the incision system in each slope area: connected, disconnected and integrated into the hydrographic network (Figure 3). The process of connected erosion, first-order channels, begins in the lowest parts of the relief and, with the help of subsurface flows, reaches higher elevations. Erosion disconnected from the drainage network begins the incision in the highest sectors of the slope and, with the predominance of surface flows, reaches the colluvium ramps further down. Finally, the integrated features are a union of previous forms, with a single incision occurring during the development of erosion (OLIVEIRA, 1989). Therefore, the possibility of two features coming together over time can be verified, by analyzing the behavior of the concentrated flow.

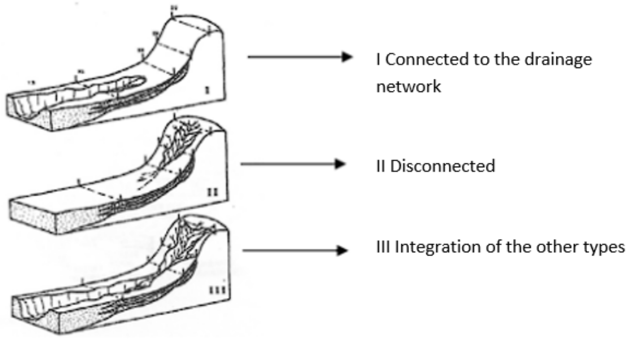

Figure 3: Evolution Model of slope types, modified from Oliveira (1989).

Another characteristic of a slope to be analyzed are its curvatures (**Erro! Fonte de referência não encontrada.**): longitudinal (in the direction of the length of the flow) and transversal (in the direction of the width of the flow). Slopes with a constant longitudinal inclination are called straight, while those that cannot be described by a simple angle can be defined as convex or concave, according to the degree of longitudinal curvature. The convex profiles, resulting from soil creep and the impact of raindrops, enhance the energy of the water flow, which is a conditioning factor for the emergence of erosive features (BIGARELLA, 2003). Concave profiles represent forms of transport and deposition equilibrium (VELOSO, 2007). The concave transverse curvature acts on the convergence of rainwater flow, while the convex transverse curvature acts on the divergence of flow (STABILE, 2008). The convergence of surface flow causes flow concentration, increasing susceptibility to the occurrence of linear erosive features (XUJIONGXIN, 1996).

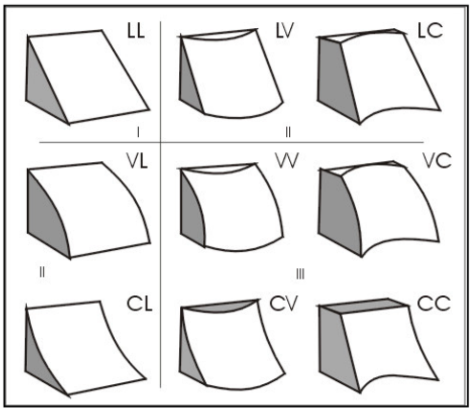

Figure 5: Geometric shapes of the slopes (LL: linear-linear; VL: convex-linear; CL: concave-linear; LV: linear-convex; LC: linear-concave; VV: convex-convex; VC: convex-concave; CV: concave-convex; CC: concave-concave) (RUHE, 1975, apud XUJIONGXIN, 1996).

4 SURVEY AND TEMPORAL ANALYSIS OF THE EVOLUTION OF LINEAR EROSION FEATURES

With the survey using satellite images, a linear erosion feature (Feature 1) was identified in Area 1 – the easternmost area (**Erro! Fonte de referência não encontrada.**), during the period

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2013 thru 2021. At the head of Feature 1 can be found one of the contour lines, constructed in order to reduce the speed of surface runoff on the slope. The concentration of flow that caused the initiation of the feature may have arisen from the overtopping of the contour line in July 2013, (**Erro! Fonte de referência não encontrada.**a) and, from 2015 (**Erro! Fonte de referência não encontrada.**b), the erosive feature evolved in the longitudinal direction of the contour line and began to accumulate heavy sedimentation (**Erro! Fonte de referência não encontrada.**c and **Erro! Fonte de referência não encontrada.**d). Feature 1 is located in the middle position of the slope, is positioned longitudinally to the steepest slope of the land, and disconnected from the drainage network. Having started as linear in shape, it then transformed into a lobed ovoid, mainly due to the concentration of flow in the contour curve; it is short in length (64 meters) and large in width (50 meters) (Table 3). Erosion is still known to be developing in the region (**Erro! Fonte de referência não encontrada.**d).

Slope position	Middle	X	Top		Bottom	
Length	Long		Medium		Short	X
Width	Wide	X	Medium		Narrow	
Line of inclination	Transversal			Longitudinal		X
Basic shape	Smooth Ovoid		Lobulated Ovoid	X	Coalescent Ovoid	
	Smooth Periform		Orthogonal		Linear	
	Others					
Evolutionary Stage	Stabilized		In Development		Corrected	X
Incision System	Connected		Disconnected	X	Integrated	
Possible Origin Influencing factors	Overtopping of the contour curve					
Curvature - (longitudinal / transversal)	Convex - linear					

Table 3: Systematization sheet for Feature 1.

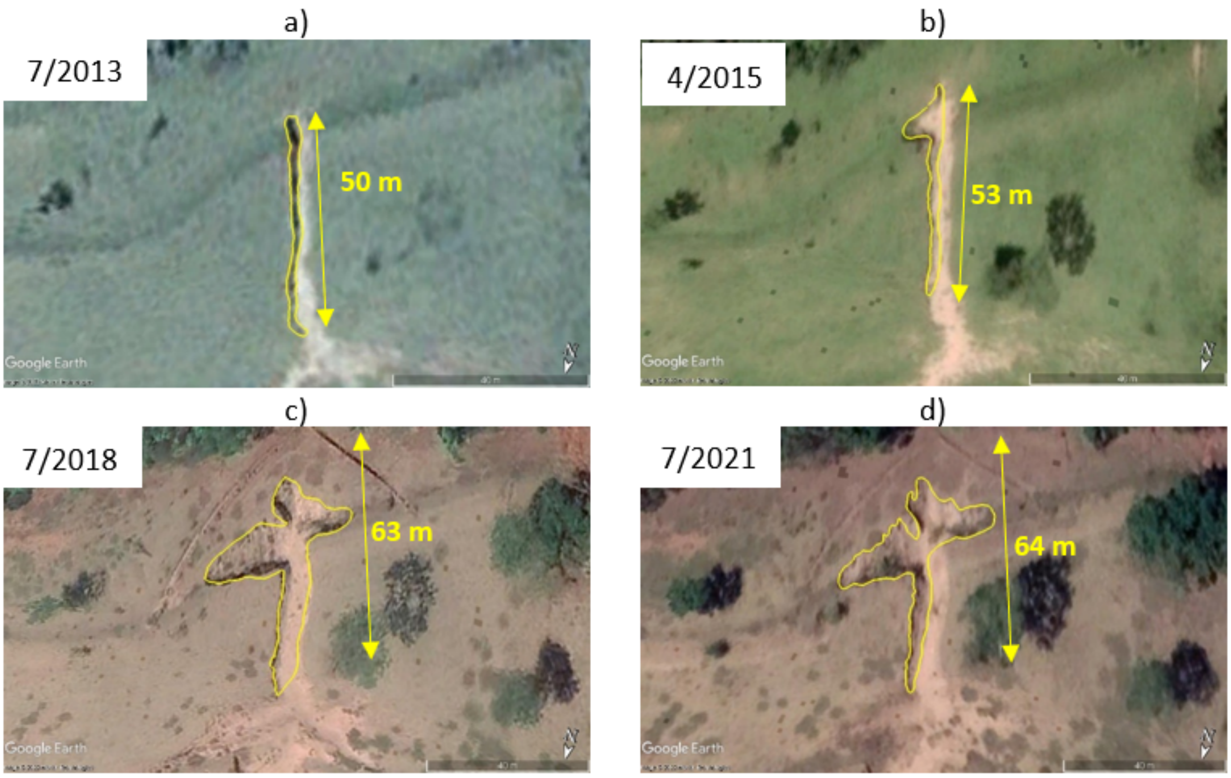

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Figure 6: Feature 1, located in Area 1: a) Situation in 2013; b) Situation in 2015; c) Situation in 2018 (concentration on the level curve); and, d) Situation in 2021.

Area 2 is defined by the portion located in the center of the study area, where in 2010 Features 2, 3 and 4 appeared. These were corrected between April 2010 and July 2013, together with the reconstruction of the contour lines. Along the constructed curves, it is possible to see, through Google Earth images, the accumulation of water and sedimentation. Feature 2 is at mid-slope, disconnected from the drainage network and occurs longitudinally at the greatest slope point. It has an ovoid lobulated shape, with a short length (54 meters) and width (6 meters) (Table 4). The dimensions of Features 3 and 4 were not easy to analyze by satellite image, and were on a low slope (Table 5). The overtopping of the contour line is a possible cause of the appearance of the features, which were corrected between 2010 and 2013, (**Erro! Fonte de referência não encontrada.**a e **Erro! Fonte de referência não encontrada.**b).

Features 5, 6 and 7 appeared at a later stage. From 2016 onwards, Feature 7 was observed close to the location of Features 3 and 4 (**Erro! Fonte de referência não encontrada.**a e **Erro! Fonte de referência não encontrada.**d). The three features have similar characteristics to Features 3 and 4 and are on the middle slope, disconnected from the drainage network and occur longitudinally to the steepest line, with a linear shape and small dimensions. Feature 6 is stabilized, while the other features in this region are, at the present time, recovered (Table 6).

Slope position	Middle	X	Top		Bottom	
Length	Long		Medium		Short	X
Width	Wide		Medium		Narrow	X
Line of inclination	Transversal			Longitudinal		X
Basic shape	Smooth Ovoid		Lobulated Ovoid	X	Coalescent Ovoid	
	Smooth Periform		Orthogonal		Linear	
	Others					
Evolutionary Stage	Stabilized		In Development		Corrected	X
Incision System	Connected		Disconnected	X	Integrated	
Possible Origin Influencing factors	Overtopping of the contour curve					
Curvature - (longitudinal / transversal)	Convex - concave					

Table 4: Systematization sheet for Feature 2.

Slope position	Middle		Top		Bottom	X
Length	Long		Medium		Short	X
Width	Wide		Medium		Narrow	X
Line of inclination	Transversal			Longitudinal		X
Basic shape	Smooth Ovoid		Lobulated Ovoid		Coalescent Ovoid	
	Smooth Periform		Orthogonal		Linear	X
	Others					
Evolutionary Stage	Stabilized		In Development		Corrected	X
Incision System	Connected		Disconnected	X	Integrated	
Possible Origin Influencing factors	Concentration of superficial runoff due to the shape of the slope.					
Curvature - (longitudinal / transversal)	Convex - concave					

Table 5: Systematization sheet for Features 3 and 4.

Figure 7: Features 2, 3, 4, 5, 6 and 7, located in Area 2: a) Situation in 2010; b) Situation in 2013 (correction of Features 2 and 3); c) Situation in 2015; d) Situation in 2016 (Emergence of Features 5, 6 and 7); e) Situation in 2018 (correction of Feature 7); and, f) Situation in 2021 (correction of Feature 5).

Slope position	Middle	X	Top		Bottom	
Length	Long		Medium		Short	X
Width	Wide		Medium		Narrow	X
Line of inclination	Transversal				Longitudinal	X
Basic shape	Smooth Ovoid		Lobulated Ovoid		Coalescent Ovoid	
	Smooth Periform		Orthogonal		Linear	X
	Others					
Evolutionary Stage	Stabilized		In Development		Corrected	X
Incision System	Connected		Disconnected	X	Integrated	
Possible Origin Influencing factors	Concentration of superficial runoff due to the shape of the slope.					
Curvature - (longitudinal / transversal)	Convex - concave					

Table 6: Systematization sheet for Features 5, 6 and 7.

In the steepest and upstream portion of Area 2, four features were identified that were impossible to classify by satellite image observation (Figure 4). There is the possibility that they are caused by either gullies or landslides, but their characteristics must be confirmed by technical visits to the site.

In Area 3, the first erosion appeared in 2010, Feature 8 (**Erro! Fonte de referência não encontrada.**a), which possibly originated from a concentration of flow in the region due to the profile of the slope, moving in the direction of the slope's steepest line. It is of short length (61 meters) and a narrow width (3 meters), of linear shape and is located on the middle slope, without connecting to the drainage channel (Table 7). In the years 2013 and 2015, Features 9, 10, 11 and 12 appeared, due to the concentration of surface flow caused by the longitudinal and transverse curvatures. Additionally, during this period, Feature 8 was partially corrected (**Erro! Fonte de referência não encontrada.**b e **Erro! Fonte de referência não encontrada.**c). In 2018, Feature 11 reappeared where the landfill had been made, Feature 10 had extended to 60 meters in length and the relocation of the existing contour line at the site could be analyzed (**Erro! Fonte de referência não encontrada.**e). In 2021 (**Erro! Fonte de referência não encontrada.**f), with the reconstruction of the contour line, Feature 10 began to increase in size, reaching a length of 62 meters (perpendicular to the contour line) and an average width of 11 meters, before increasing another 68 meters in the direction of the curve, that is, transversely in the direction of greatest inclination, therefore establishing a total length of 130 meters. As a consequence, this feature is now linear in form, composed of coalescence, disconnected from the network and still under development (Table 9).

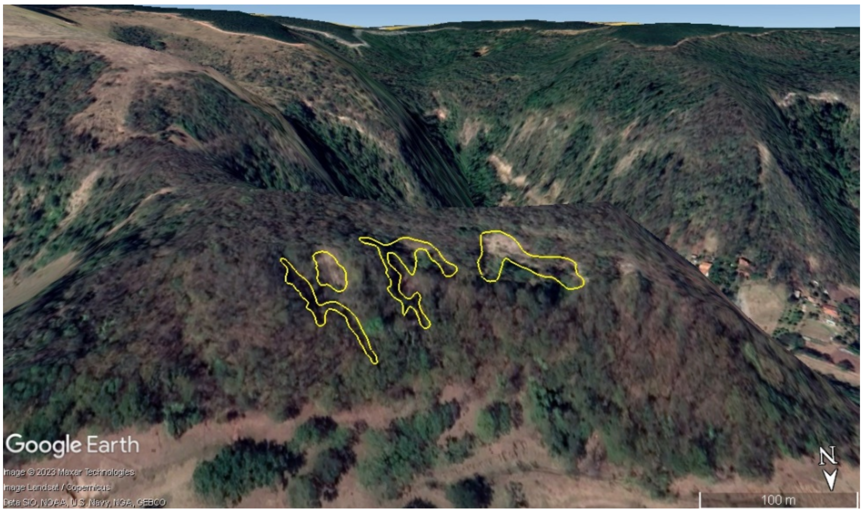

Figure 4: Erosion features not classified in the year 2022.

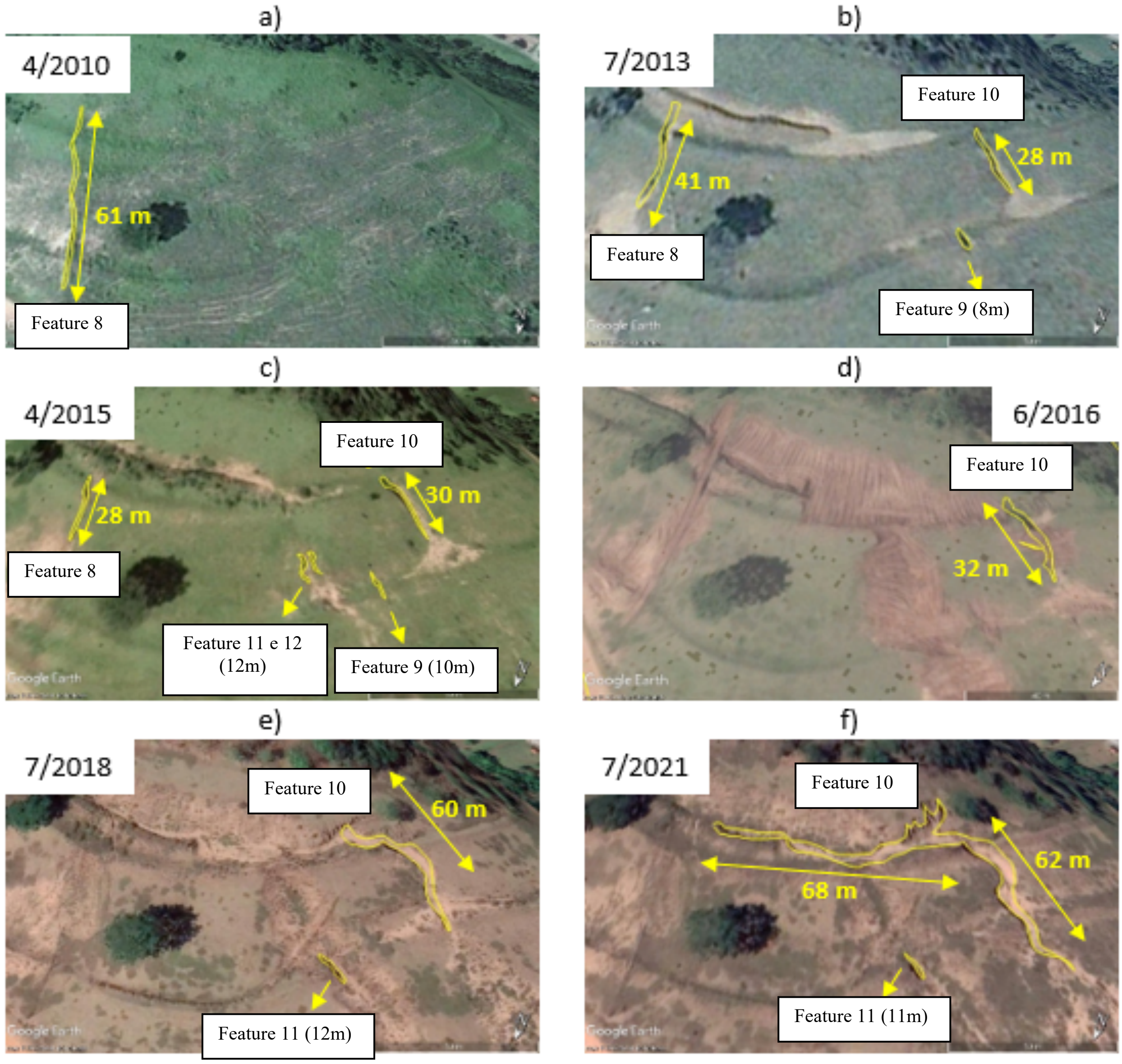

Figure 9: Features 8, 9, 10 and 11, located in Area 3: a) Situation in 2010 (emergence of feature 8); b) Situation in 2013 (emergence of features 9 and 10); c) Situation in 2015 (emergence of features 11 and 12); d) Situation in 2016 (correction of contour lines and features 9, 11 and 12); e) Situation in 2018 (reappearance of feature 11); and, f) Situation in 2021.

Features 9, 11 and 12 have similar characteristics, being entirely linear, of small dimensions and located on the mid-slope. They are also currently stabilized. Features 9 and 12 were corrected between 2015 and 2016, while 11 shows no evolution (Table 9).

Slope position	Middle	X	Top		Bottom	
Length	Long		Medium		Short	X
Width	Wide		Medium		Narrow	X
Line of inclination	Transversal			Longitudinal		X
Basic shape	Smooth Ovoid		Lobulated Ovoid		Coalescent Ovoid	
	Smooth Periform		Orthogonal		Linear	X
	Others					
Evolutionary Stage	Stabilized		In Development		Corrected	X
Incision System	Connected		Disconnected	X	Integrated	
Possible Origin Influencing factors	Concentration of superficial runoff due to the shape of the slope.					
Curvature - (longitudinal / transversal)	Convex - concave					

Table 7: Systemization sheet for Feature 8.

Slope position	Middle	X	Top		Bottom	
Length	Long		Medium	X	Short	
Width	Wide		Medium	X	Narrow	
Line of inclination	Transversal		X	Longitudinal		X
Basic shape	Smooth Ovoid		Lobulated Ovoid		Coalescent Ovoid	
	Smooth Periform		Orthogonal		Linear	
	Others					
Evolutionary Stage	Stabilized		In Development	X	Corrected	
Incision System	Connected		Disconnected	X	Integrated	
Possible Origin Influencing factors	A priori, overtopping of the level curve, a posteori, flow concentration in the direction of the level curves.					
Curvature - (longitudinal / transversal)	Concave - convex					

Table 8: Systemization sheet for Feature 10.

Slope position	Middle	X	Top		Bottom	
Length	Long		Medium		Short	X
Width	Wide		Medium		Narrow	X
Line of inclination	Transversal			Longitudinal		X
Basic shape	Smooth Ovoid		Lobulated Ovoid		Coalescent Ovoid	
	Smooth Periform		Orthogonal		Linear	X
	Others					
Evolutionary Stage	Stabilized	X	In Development		Corrected	
Incision System	Connected		Disconnected	X	Integrated	
Possible Origin Influencing factors	Concentration of superficial runoff due to the shape of the slope.					
Curvature - (longitudinal / transversal)	Convex - convex					

Table 9: Systemization sheet for Features 9, 11 and 12.

A summary with the main characteristics of the features surveyed is presented in Table 1. The summary considered the largest dimensions for the features that appeared on more than one date in the images. The analysis of the data compiled in the table indicated that, in general, the incidence of erosive features occurred mainly on the middle slope (in 9 of 12), with relief of convex longitudinal curvature in approximately 83% and concave transversal in approximately 58% of the slope cases. The length of 11 of the 12 features was classified as short, with only one (Feature 10) classified as medium. While the width of 10 of the 12 features was classified as narrow, two (Feature 1 and Feature 10) classified as large. Some of the features were recovered during the period of analysis, and did not increase their dimensions. Thus, from the survey carried out in terms of the relief, the tendency for erosive features to occur on the middle slope (75%) was noted: in convex longitudinal curvature (83%) and concave transverse curvature (58%).

Feature	Position on the slope	Greatest length reached (m)	Width (m)	Curvature (vertical/horizontal)
Feature 1	Middle	64 (short)	50 (wide)	Convex/straight
Feature 2	Middle	54 (short)	6 (narrow)	Convex/concave
Feature 3	Bottom	10 (short)	1.5 (narrow)	Convex/concave
Feature 4	Bottom	5 (short)	1 (narrow)	Convex/concave
Feature 5	Middle	11 (short)	2 (narrow)	Convex/concave
Feature 6	Middle	25 (short)	3 (narrow)	Convex/concave
Feature 7	Bottom	20 (short)	2 (narrow)	Convex/concave
Feature 8	Middle	61 (short)	3 (narrow)	Convex/concave
Feature 9	Middle	10 (short)	2 (narrow)	Convex/convex
Feature 10	Middle	130 (medium)	50 (wide)	Concave/convex
Feature 11	Middle	12 (short)	1 (narrow)	Convex/convex
Feature 12	Middle	12 (short)	1 (narrow)	Concave/convex

Table 1: Summary of the characteristics of the Features.

Although only one feature had a length classified as medium, reaching 130m, three further features reached lengths greater than 54m, with the others reaching a maximum length of 25m. Thus, analyzing the 4 features with the longest lengths, it can be seen that Feature 1 and Feature 10 were classified as having a large width (50 m), while Feature 2 and Feature 8 had widths of 6 m and 3 m, respectively. The four features are located on the middle slope. Considering the relief classification, three of these features have convex longitudinal curvature (Feature 1, Feature 2 and Feature 8), with Feature 2 and Feature 8 having concave transverse curvature. Feature 10 was the only one classified as having concave longitudinal and convex transverse curvature. Therefore, convex longitudinal curvature may be an indication of greater development of the linear erosion feature, while the transverse curvature result is inconclusive.

The highest incidence of erosion in convex longitudinal relief is expected (BIGARELLA, 2003; VELOSO, 2007). The occurrence of two of the features analyzed in concave longitudinal relief may be due to the preference of cattle passing through this type of relief over the contour line, causing soil compaction destruction and consequent concentration of flow. Most of the features surveyed, including two of the largest analyzed, are in relief with concave transverse curvature. This result is also expected, since concavity determines the concentration of flow (STABILE, 2008; XUJIONGXIN, 1996).

It is important to consider, first of all, that although the development of pasture tends to preserve diffuse flow, it can be converted into concentrated flow in areas of ditching, paths, or as a result of cattle trampling and annual crops that expose the soil to the action rainwater, therefore causing slope lengthening or linear features (FURLANI, 1980). As previously established, areas with conventional soil preparation and without vegetation cover are more susceptible to water erosion, considering that incorrect use of the soil favors surface sealing, the formation of a compacted soil layer that makes water infiltration difficult (PANACHUKI, 2011; BORGES-TERRERO *et al.*, 2019).

Thus, the analysis leads to the observation that the highest incidence is in the average, rather than in the low range. This fact can be explained, on the one hand, by the low slope area being far from drainage channels and, on the other hand, the incidence of erosive features on the middle slope may indicate the need for attention regarding some of the conservation practices of the soil, essentially of an edaphic nature. The survey carried out indicated that mechanical (terracing) and vegetative (forestation and pasture) conservation practices be established, in addition to regular corrections of erosion features throughout the period of observation. However, the erosion control currently practiced has been proven to be insufficient: soil practices are required "which replace nutritional elements, control the combustion of organic matter, reduce leaching, controlling, in part, the causes of soil depletion" (BERTONI and LOMBARDI NETO, 2014). Periodic soil analyzes of the area under investigation should be able to indicate the soil corrections needed to reduce the incidence of erosive features in the area. Silva *et al.* (2015) also suggest agroecological practices, such as the use of alternative products to combat pests and organic and chemical fertilization with agronomic prescriptions.

Additionally, although it is noted that the existing forest in the region is correctly distributed along the slope, in the region with the greatest slope, the top of the hill consists of pasture. Bertoni and Lombardi Neto (2014) recommend the formation of forests precisely at the top of the hills with the aim of reducing the floods formed at the headwaters, which can cause erosion in the steepest parts of a slope.

5 FINAL CONSIDERATIONS

It could be concluded that the sample area studied in this article is one susceptible to erosion processes, given the various linear erosion features found over the last decade, irrespective of the presence of vegetation cover or not. Being a headwater area of the Batalha River basin, with a top to middle slope predominance, it is arguably an environment that is more prone to the emergence of linear erosion features. Of note is the predominance of vertical/horizontal convex-concave curvatures, which increase the accumulated energy of the surface flow and, consequently, increase the speed of concentrated flow. Thus, the conditions presented, together with the sandy-textured soil, are factors liable to result in the evolution of linear erosion processes.

In addition, the land use and occupation, such as the removal of vegetation cover and greater soil compaction due to agropastoral practices, can be highlighted as a conditioning factor in accelerating the process of linear erosion formation.

Mitigating techniques were observed along the slope during site visits. Among them, palliative measures such as the construction of contour lines and the removal of inhibitory plants and grounding, were notable. However, an overtopping of the level curves and a consequent accumulation of water in Areas 2 and 3 was observed, demonstrating that these correction attempts have been insufficient to the task of combatting the evolution of existing or the occurrence of new linear erosion features, although it was further noted that all the linear erosions within the sample are disconnected from the drainage system, which may mitigate the consequences of erosion evolution.

The study, carried out in the Jacutinga Hills, provided the means to sample and systematize linear erosion features, and better understand the behavior and causes of such features over the period of a decade. Based on the work undertaken, a study of geomorphology in the headwaters of the Batalha River could be developed to analyze the behavior of preferential flow lines and a prognosis for the erosion processes of features in the region. And, thus, assertive corrective measures could be established to prevent the evolution of linear erosions.

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