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# Characterization and Analysis of Gullies in the Sub-basin of Ribeirão Serra in Morrinhos, Goias, Brazil

Breno A. da Silva[1], Pedro R. Giongo[2], Thais A. Barbosa[3], Victor H. Moraes[4], Thomas J. Cavalcante[4], Clarice Backes[5] & Alessandro J. M. Santos[5]

[1] State University of Goias, Morrinhos, Brazil

[2] School of Agricultural Engineering, State University of Goiás, Santa Helena de Goiás, Brazil

[3] Federal University of Goiás, Goiania, Brazil

[4] Goiano Federal Institute, Rio Verde, Brazil

[5] State University of Goias, São Luis de Montes Belos, Brazil

Correspondence: Pedro R. Giongo, School of Agricultural Engineering, State University of Goiás, Santa Helena de Goiás, Brazil. Tel: 55-649-8114-1606. E-mail: pedro.giongo@ueg.br

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**Abstract**

Due to the reduction of the vegetation cover, the exposed soil increases the erosive vulnerability, and reduces the organic matter content, factors that can aggravate with less production of vegetal mass and microbiological activity of the arable layers, rich in calcium carbonate and that increases the degradation of the soil structure leading to the formation of gullies. This study aimed to characterize and survey the physical, chemical and structural characteristics of soils of four gullies located in the sub-basin of Ribeirao Serra by means of physical-chemical parameters and subjected to multivariate analysis. Slope maps, hypsometry, drainage network and soil types were elaborated. Morphological description of the soil, georeferencing of the boundaries of each gullie, and collection of deformed soils samples for physical-chemical and structural analysis were performed. Soil samples were collected on the slopes of the gullies at three points of each erosion, with three replicates, one in each horizon (A, B and C) at depths ranging from 0 to 310 cm. Qualitative tests were also carried out to verify the presence of some substances in the soil, such as carbonates and manganese. The data were submitted to the multivariate analysis, by means of Discriminant Analysis of Partial Least Squares analysis to evaluate the grouping of gullies in relation to the analyzed elements (physical-chemical), identifying if the set of elements interact with each other and/or present similarities. There is a high degree of anthropization with the use of pasture cultivated around the four gullies studied. According to the multivariate analysis the gullies Barreiro, Vendinha and Capim, are different, while it resembles the gull of the Retreat with the gullies Vendinha and Capim. The chemical elements present greater weight than the physical ones, in the separation of the gullies through the multivariate model.

**Keywords:** deforestation, remote sensing, gullies, multivariate analysis

## 1. Introduction

The central west of State of Goiás, Brazil, is characterized by dynamic changes in the use and occupation of the soil with the transition from natural areas to areas occupied by pastures, agriculture (soybean and corn) and sugarcane cultivation (Cunha et al., 2012; Loarie et al., 2011). These changes promote changes in the pattern of biophysical variables (Moraes et al., 2019), causing sedimentation of reservoirs, water courses and losses of fertile soils. Due to the reduction of the vegetation cover, the exposed soil is vulnerable to intense rains (Peter et al., 2014; Assis et al., 2017), reducing the organic matter content, effective soil depth, enriching layers calcium carbonate and soil structure degradation (Martinez-Cassanovas & Ramos, 2009). There is also acidification of soil, nutrient exhaustion and decrease of organic carbon content and socioeconomic and environmental biodiversity (Carneiro et al., 2009).

Among the erosive features, the gullies constitute the most severe erosive feature of the soil and the one that causes the greatest damage, since they are of great destructive power and their recovery is slow and difficult to control (Kheir et al., 2008; Shuwen et al., 2015). Very degraded areas, such as gullies, hinder natural revegetation due not only to the continuous erosive processes, but also to the scarcity of nutrients and organic matter, besides the possible absence or limitation of propagules of the previous plant community, being necessary anthropic revegetation measures (Peters et al., 2006). Due to the damages caused by the gullies to the environment, the study of gullies is very important in the definition of its origin, evolution and its forms of containment, looking for a way so that it does not cause more harm to the soil.

The evaluation of soil physical and chemical attributes in environments degraded by water erosion is of great importance due to the sensitivity to changes in soil quality, where it can provide subsidies for the establishment of rational management systems and contributions to the maintenance of sustainable ecosystems (Carneiro et al., 2009). Thus, any modification in the soil can directly alter its structure and, consequently, its fertility, with reflections on environmental quality and crop productivity (Brookes, 1995). Information about these indicators in gully environments is little known, or nonexistent, and there is a need for studies for a future relationship between physical and chemical attributes with soil biological indicators, helping to monitor environments degraded by water erosion.

The Geographic Information Systems (GIS), together with geoprocessing techniques and remote sensing have contributed greatly to the spatial-temporal monitoring of gullies (Shuwen et al., 2015). They allow the analysis of phenomena at different scales and allow simulating situations and environmental planning for decision-making (Zanata, 2012). In view of the above, this study aimed to characterize the Ribeirão Serra sub-basin, (ii) to survey the physical, chemical and structural characteristics of soils in four gullies located in the sub-basin, and (iii) separation of gullies through multivariate analysis and chemical and physical characteristics.

## 2. Method

### 2.1 Study Area

This study was carried out in four Gullies located in the Sub-basin of Ribeirão da Serra, which belongs to the Meia Ponte river basin, in a rural area of the municipality of Morrinhos-GO (Figure 1). The climate of the region is classified according to Koppen-Geiger type Aw (tropical subhumid), with rainy season in the winter version and drought, with average rainfall of 1.4423 mm (Alvares et al., 2013). Between October and April in this region, there is an increase in the possibility of new erosion and expansion of existing ones, due to the process of water erosivity being more intense during this rainy period.

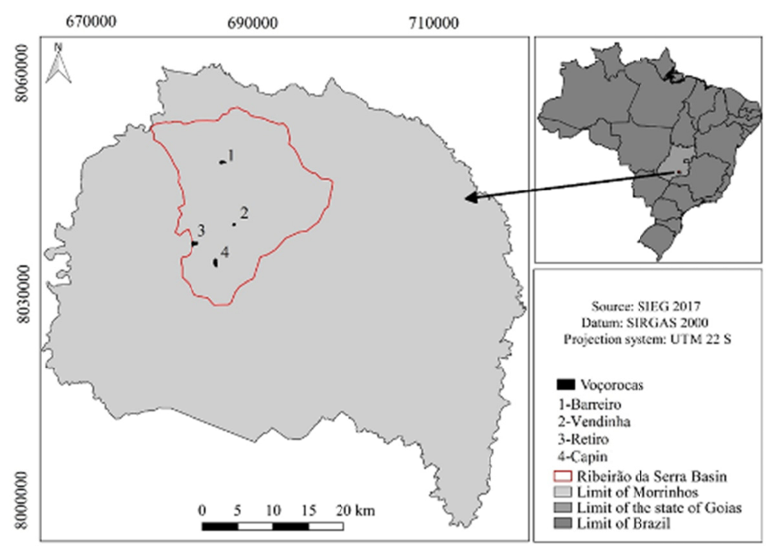


Figure 1. Geographic location of the gullies in the Ribeirão da Serra Basin, Morrinhos, Goias Brazil

### 2.2 Characterization of the Object of Study

To order the sequence of erosions for structuring the research and writing of this study, the data were collected and analyzed according to the position of the gullies (North-South) and routes that interconnect them. The initial point was the Gullie do Barreiro, following to Gullie da Vendinha, Retiro, and to the south the Gullie do Capim (Figures 1 and 2).

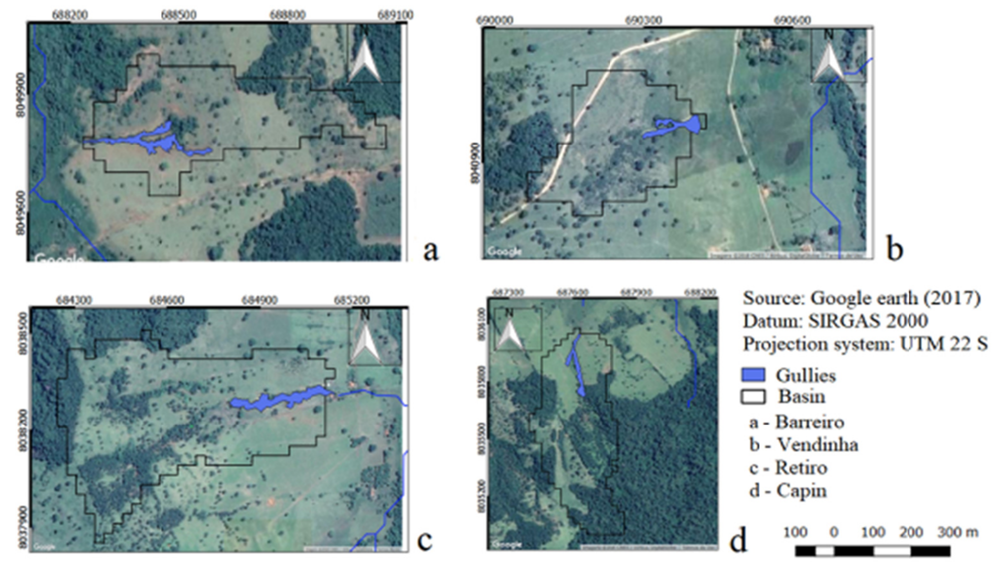


Figure 2. Geographic location of the Barreiro, Vendinha, Retiro and Capim gulls, in a satellite image (Google Earth) and basin area contributing to the gutter channel

Altimetry data were obtained from the cartographic base of the National Institute of Space Research (INPE, 2017) for the mapping of slope, hypsometry and drainage network. Soil and boundary data from river basins were made available by the State Geoinformation System (SIEG, 2017). These maps were generated in QGIS software (QGIS Development Team, Boston, USA). Landsat-8 satellite images (orbit 222, point 72) with passage on April 10, 2017 obtained from the INPE image catalog were used to aid in the identification of the vegetation cover. Images of Google Earth (Google Inc., California, USA) were used to aid in the identification of land use around gullies. Thematic maps of geographic location, hydrography, drainage, soil, slope and hypsometry were developed.

### *2.3 Erosion Characterization and Analysis*

Technical visits were carried out in the erosions to identify and characterize the natural and anthropic elements that can influence the emergence and evolution of erosive incisions. Morphological description of the soil, georeferencing of each gullie with GNSS receiver of topographic class of the limits of each gullie and collection of samples of deformed soils for physical-chemical and structural analyzes. Soil collections in the gullies followed the methodology described by Santos et al. (2015). In the soil collection there was a previous cleaning of the slope advancing at least 10 cm to the inside of the edge to minimize the interference of the exposed soil change. Soil samples were collected on the slopes of the gullies at three points of each erosion, with three replicates, one in each horizon (A, B and C) at depths ranging from 0 to 310 cm. Each sample consisted of a volume of 3 kg of soil. In the upper third of the Barreiro voorah an additional sample was collected (R) to identify if at this point the gull had already reached the rock. The horizons were established from the textural and color change along the profile. The analyzes for physical-chemical characterization of soils were sent to a specialized laboratory and all analyzes were performed according to Embrapa Solos methodology, in their Manual of Soil Analysis Methods (Embrapa, 2011). For laboratory analysis, 1 kg of soil was used for each sample. The rest of the collected sample was used to define the color, texture, cementation and soil consistency, following Santos et al. (2015). The soil color analyzes were performed according to the Munsell Letter (Munsell Soil Color Company, 1950). Qualitative tests were also carried out to verify the presence of some substances in the soil, such as carbonates and manganese. After the application of drops of Hydrochloric Acid (10% HCl) and Hydrogen Peroxide (20 volumes), they were evaluated (Santos et al., 2015).

#### 2.3.1 Multivariate Analysis of Soil Physical and Chemical Data

The data were submitted to the multivariate analysis, through the treatment of Discriminant Analysis of Partial Least Squares (PLS-DA), through MetaboAnalyst processing (2018). The treatment of the data from the PLS-DA was used to evaluate the grouping of gullies on the analyzed elements (physical-chemical), identifying if the set of elements interact with each other and/or have similarities. The results of the chemical and physical analyzes of the soils were grouped for the four gullies.

## 3. Results and Discussion

The watershed of Ribeirao Serra has Ribeirao Serra as a fifth-order watercourse (Figure 3a). The Barreiro gull is connected to the stream that receives the same name. The Vendor voororoca is directed to Ribeirão Serra, but is not connected to the watercourse. In the same way it occurs with the gullies of the Retreat and Capim. These last two are tributaries of streams that receive the same denominations of these erosions (Figure 3a). In the eroded areas the highest presence is of Red Argisol and Red Oxisoil (Figure 3b), being deeper soil with better drainage capacity. In Gullie do Barreiro, the predominant soil is Haplus Cambisol, with a small variation occurring in the lower third of the gully where it is possible to find Gleissolo Haplico, and at the top of the erosion there is also the Red Oxisoil. Gullie da Vendinha occurred in soil classified as Cambissolo moved, favorable to erosive processes. The Gullies do Retiro and Capim are located in areas with a predominant Cambisol, in addition to the occurrence of deep Latosol (Figure 3b). Erosion formations occur predominantly in soils with characteristics of greater vulnerability (latosol, argisol and cambisol) also observed by Werlang (2000). Marques et al. (2014) also mention that the increase of the gullies alter the characteristics of the landscape, reducing the conditions of reestablishment of the landscape, in addition to the productive conditions.

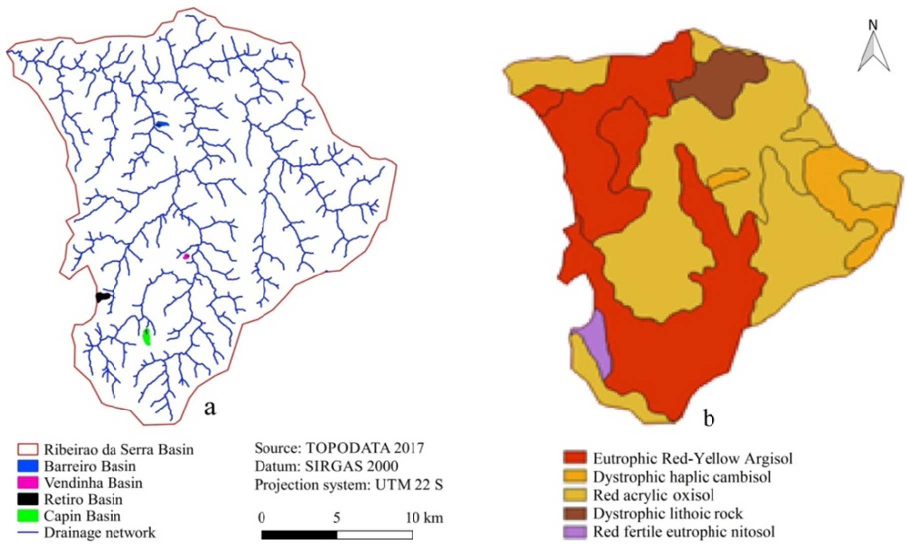


Figure 3. Map of the drainage network (a) and type of soil (b) predominant in the Ribeirão da Serra basin in the municipality of Morrinhos, Goias-Brazil

The sub-basin of Ribeirão da Serra is composed of predominant vegetation of the Cerrado type Stricto Sensu, Cerradão, Campo Sujo and Campo Cerrado, besides the presence of Riparian forests. In spite of the declivity (Figure 4a) in the studied areas, it is not favorable to agricultural development, the production system with the most prominence in the region close to the four erosions is mainly agricultural activity. The gullies of Barreiro and Vendinha presented a declivity of approximately 15%, while the gullies of the Retreat presented a slope varying from 3 to 15%. The slope of the Gullie do Capim at its head is 30%, in the middle stretch it is 15% and downstream 8% (Figure 4b). The Barreiro and Vendinha gulls are located in areas with lower altitudes while the erosion of the Retreat and Capim are located in areas with higher altitudes (Figure 4b). The gorge of the Retreat is the largest erosion in an eroded area among the four studied, with 9,274 m², while the smallest of the gullies is that of Vendinha with a total area of 2,219 m² (Figure 2).

Therefore, the slope, associated with the physical characteristics of the soils, are factors that can potentiate the occurrence and increase of the gullies, the soils through the physical characteristics, while the slope promotes concentration and increases the velocity of surface water over the surface. The slope of the area was also pointed out by Oliveira et al. (2013), as one of the main factors is the formation of gullies that start as gullies and increase to gullies due to the conditions of water concentration (contribution basin) associated to low or no cover protection of the soil.

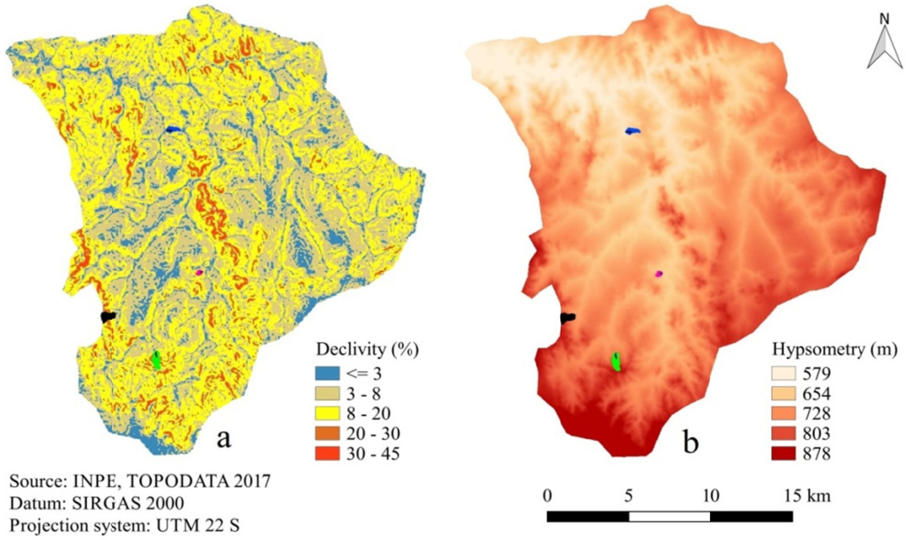


Figure 4. Map of slope (a) and hypsometry (b) of the Ribeirao da Serra basin in the municipality of Morrinhos, Goias, Brazil

### *3.1 Thickness and Arrangement of the Gullies Horizons*

The depth variation of the C horizon in Gullie do Barreiro was the one that most stood out, beginning in the third higher than 70 centimeters, in the middle third 110 centimeters and not inferior to 150 centimeters (Table 1). In Gullie da Vendinha, the highlight was the depth of the C horizon in the upper third reaching 140 centimeters, different from the other stretches where the C horizon was found at 70 centimeters. In the gullie do Retiro, the greatest difference was in the B horizon of the middle third, reaching depths between 50 and 200 centimeters, while the others of the same horizons were found between 50 and 150 centimeters. In Gullie do Capim, the B horizon of the upper third was the one that most stood out, being found between 40 and 220 centimeters.

The Barreiro gull is the one with the highest average depth for the horizons identified, compared to the other gullies. In general, shallower soils have low water drainage capacity, as well as the formation of the root system of plants in the area, which are associated with the ability to protect the soil on the surface. Oliveira et al. (2013), mention that the vegetation cover protects against the impact of rain drops as well as decreasing the soil's potential for surface runoff.

Table 1. Thickness and arrangement of the gullies horizons

| Third | Horizon | Gullie Barreiro | | Gullie Vendinha | | Gullie Retiro | | Gullie Capim | |
|---|---|---|---|---|---|---|---|---|---|
| | | D (cm) | T (cm) | D(cm) | T (cm) | D (cm) | T (cm) | D(cm) | T (cm) |
| Higher | A | 0-40 | 40 | 0-30 | 30 | 0-40 | 40 | 0-40 | 40 |
| | B | 40-70 | 30 | 40-140 | 100 | 50-120 | 70 | 40-220 | 180 |
| | C | 70-310 | 240 | $140^+$ | - | $150^+$ | - | $220^+$ | - |
| | R | $310^+$ | - | - | - | - | - | - | - |
| Medium | A | 0-50 | 50 | 0-28 | 28 | 0-50 | 50 | 0-15 | 15 |
| | B | 50-100 | 50 | 30-70 | 40 | 50-200 | 150 | 15-40 | 25 |
| | C | $110^+$ | - | $70^+$ | - | $200^+$ | - | $40^+$ | - |
| Bottom | A | 0-30 | 30 | 0-30 | 30 | 0-50 | 50 | 0-20 | 20 |
| | B | 30-150 | 120 | 30-70 | 40 | 70-150 | 50 | 20-100 | 80 |
| | C | $150^+$ | - | $70^+$ | - | $170^+$ | - | $100^+$ | - |

*Note.* * D = Depth; T = Thickness.

### *3.2 Analysis of Soil Color and Consistency*

The color classification of the gull horizons by means of the Munsell chart is shown in Table 2. The results of the analysis of consistency of wet and wet soil by horizon of the soils of the gullies are in Table 3.

Table 2. Classification of soil color of the gullies horizons acording of Munsell carta

| Third | Horizon | Barreiro Gullie | | Vendinha Gullie | | Retiro Gullie | | Capim Gullie | |
|---|---|---|---|---|---|---|---|---|---|
| Higher | A | 2.5YR 2.5/3 | Dark reddish brown | 7.5YR 6/3 | Light brown | 5YR 3/3 | Dark reddish brown | 7.5YR 5/3 | Brown |
| | B | 2.5YR 3/6 | Dark red | 10YR 6/4 | Light yellowish brown | 5YR 3/2 | Dark reddish brown | 5YR 3/4 | Dark reddish brown |
| | C | 2.5YR 4/8 | Red | 10YR 7/6 | Yellow | 7.5YR 6/8 | Reddish yellow | 5YR 4/3 | Reddish brown |
| | R | 10YR 5/6 | Yellowish brown | - | - | - | - | - | - |
| Medium | A | 2.5YR 3/3 | Dark reddish brown | 10YR 5/2 | Grayish brown | 5YR 4/3 | Reddish brown | 7.5YR 4/2 | Brown |
| | B | 2.5YR 3/4 | Dark reddish brown | 7.5YR 5/1 | Gray | 2.5YR 3/3 | Dark reddish brown | 5YR 3/4 | Dark reddish brown |
| | C | 7.5YR 5/8 | Strong brown | 2.5Y 8/2 | Pale yellow | 7.5YR 5/6 | Strong brown | 5YR 4/6 | Yellowish red |
| Bottom | A | 10R 4/3 | Grayish red | 2.5YR 5/3 | Reddish brown | 7.5YR 4/3 | Brown | 5YR 4/3 | Reddish brown |
| | B | 10R 3/2 | Dusky red | 10YR 5/2 | Grayish brown | 10YR 3/3 | Dark brown | 7.5YR 5/4 | Brown |
| | C | 2.5YR 3/3 | Dark reddish brown | 2.5Y 8/1 | White | 2.5Y 5/4 | Light olive brown | 7.5YR 3/4 | Dark brown |

The consistency of the soil is conditioned by the adhesion and cohesion forces, being dependent on soil moisture. In this study, soil stickiness and friability were classified as loose, very friable, friable, firm, very firm, extremely firm (Table 3). The textural composition of the soil is an important factor for the study of erodibility due to the processes of disintegration and sediment transport. Soils with higher clay composition are more resistant to particle disintegration due to their plastic characteristics with greater cohesion between the particles and greater water retention capacity, avoiding soil wear through surface runoff (Spohr et al., 2009). Like fine sand, silt also presents textural composition vulnerable to erosive processes. The sand can be easily transported, has low water retention and facilitates drainage between the pores, and the silt has a higher percentage, increases the erosive susceptibility due to crust formation in the superficial part of the soil, reducing infiltration and increasing the surface runoff, a common example in the Cerrado Latosol (Belém et al., 2014).

Table 3. Consistency of moist and wet soil by horizon of soils of the gullies of the Ribeirao Serra sub-basin

| Third | Horizon | Barreiro | Vendinha | Retiro | Capim |
|---|---|---|---|---|---|
| Higher | A | Crispy and slightly sticky | Very friable and slightly sticky | Very firm and not sticky | Very firm and slightly sticky |
| | B | Crispy and sticky | Crispy and slightly sticky | Very firm and not sticky | Firm and slightly sticky |
| | C | Very firm and very sticky | Very friable and slightly sticky | Very firm, plastic and sticky | Extremely firm and slightly sticky |
| | R | Extremely firm | - | - | - |
| Medium | A | Crispy and very sticky | Steady and sticky | Crispy and sticky | Very friable and payable |
| | B | Crispy and very sticky | Firm and slightly sticky | Very friable and slightly sticky | Crispy and slightly sticky |
| | C | Steady and very sticky | Firm and slightly sticky | Crispy, slightly plastic and sticky | Crispy and sticky |
| Bottom | A | Crispy and not sticky | Crispy and slightly sticky | Very firm and sticky | Crispy and sticky |
| | B | Firm and non-sticky | Firm and non-sticky | Very firm, slightly plastic and sticky | Crispy and slightly sticky |
| | C | Steady and sticky | Extremely firm and non-sticky | Very firm, slightly plastic and sticky | Crispy and not sticky |

### *3.3 Chemical Composition Analysis*

From the analysis of the laboratory results of erosions (Table 4), the level of calcium in the superficial layers of the horizons is high, except for Gullie da Vendinha, which has an adequate level of this nutrient. This is explained by the fact that calcium is essential for plant growth, however, in acid soils such as those studied, although the calcium level is high, it is not available to plants due to the chemical competition for the hydrogen ion (Silveira & Monteiro, 2011).

Table 4. Chemical composition of the soils by horizons of the Barreiro, Vendinha, Retiro and Capim gulls, in the Ribeirão Serra basin, Morrinhos, Goiás, Brazil

| Third | Hor. | Barreiro Gullie | | | | Vendinha Gullie | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | pH | Ca | Mg | CTC | pH | Ca | Mg | CTC |
| | | $CaCl_2$ | ---------- cmolc dm³ ---------- | | | $CaCl_2$ | ---------- cmolc dm³ ---------- | | |
| Higher | A | 5.7 | 12.6 | 1.5 | 16.56 | 5.1 | 4.7 | 1.4 | 9.80 |
| | B | 5.9 | 10.8 | 1.6 | 14.55 | 5.3 | 2.8 | 1.1 | 6.06 |
| | C | 6 | 6.6 | 1.8 | 10.16 | 5.2 | 1.0 | 0.4 | 2.41 |
| Medium | A | 5.7 | 12.9 | 1.2 | 17.11 | 4.8 | 2.7 | 1.0 | 7.86 |
| | B | 6 | 12.4 | 1.6 | 15.88 | 5.0 | 3.0 | 1.3 | 7.01 |
| | C | 6.2 | 12.7 | 2.1 | 16.4 | 4.5 | 1.1 | 0.6 | 5.58 |
| Bottom | A | 5.2 | 10 | 1.5 | 16.3 | 5.1 | 5.3 | 1.3 | 9.98 |
| | B | 5.7 | 10.8 | 1.6 | 14.66 | 5.4 | 4.4 | 1.6 | 8.20 |
| | C | 6.2 | 9.3 | 1.7 | 13 | 5.3 | 3.3 | 1.5 | 6.97 |
| Mean | | 5.84 | 10.90 | 1.62 | 14.96 | 5.08 | 3.14 | 1.13 | 7.10 |
| Standard deviation | | 0.29 | 1.95 | 0.23 | 2.08 | 0.27 | 1.41 | 0.38 | 2.18 |
| Third | Hor. | Retiro Gullie | | | | Capim Gullie | | | |
| | | pH | Ca | Mg | CTC | pH | Ca | Mg | CTC |
| | | $CaCl_2$ | ---------- cmolc dm³ ---------- | | | $CaCl_2$ | ---------- cmolc dm³ ---------- | | |
| Higher | A | 5.4 | 15.1 | 1.4 | 20.50 | 5.4 | 16.4 | 1.5 | 21.72 |
| | B | 5.8 | 9.5 | 1.4 | 12.91 | 6.0 | 11,8 | 1.5 | 15.26 |
| | C | 6.0 | 9.7 | 1.8 | 13.73 | 5.8 | 12.8 | 1.6 | 16.78 |
| Medium | A | 5.6 | 19.5 | 1.4 | 23.55 | 5.1 | 16.3 | 1.7 | 21.22 |
| | B | 5.9 | 18.8 | 1.7 | 22.29 | 5.7 | 14.1 | 1.5 | 17.60 |
| | C | 5.8 | 15.6 | 1.5 | 19.05 | 5.6 | 10.5 | 1.9 | 13.88 |
| Bottom | A | 5.5 | 14.1 | 1.4 | 17.90 | 6.1 | 11.2 | 1.7 | 14.26 |
| | B | 5.6 | 12.9 | 1.5 | 16.36 | 5.1 | 11.5 | 1.6 | 15.48 |
| | C | 5.7 | 6.3 | 1.6 | 9.45 | 5.4 | 10.4 | 1.7 | 14.39 |
| Mean | | 5.70 | 13.50 | 1.52 | 17.30 | 5.58 | 12.78 | 1.63 | 16.73 |
| Standard deviation | | 0.18 | 4.14 | 0.14 | 4.37 | 0.34 | 2.19 | 0.12 | 2.77 |

The lower pH values indicated the presence of free acids and the larger ones indicated the presence of saline or limestone soils. All samples indicated pH lower than 7, characterizing that all these sampled soils are considered acidic (Table 4). In relation to the soil organic matter analysis, horizon A was the horizon that presented the highest concentration of organic matter. Higher level of organic matter in horizon A is essential for plant productivity as an effective measure for the recovery of erosive processes (Bertolani & Vieira, 2001).

The organic matter content in the A horizon of the Gullie do Capim was higher than the others, which presented values equal to or less than 3.5%. For the soil to be considered as erodible, the percentage of organic matter should not exceed 3.5% (Schaefer et al., 2002). The organic matter content in the most superficial horizons (A) was expected from the other horizons, due to the material made available to the soil with the fall of leaves of trees and of the undergrowth or by the drying of grass.

The more intense the decomposition of organic matter, the greater the aggregating effect on the soil, because it gives rise to pluronic acids, which help in the formation of a more rigid soil structure. In addition to aggregating substances, organic matter provides soils with organic acids and alcohols, which are sources of carbon for microorganisms, thus favoring their life. The presence of these organisms in the soil helps in the decomposition of substances and the generation of compounds that support the healthy growth of plants (Primavesi, 2002).

### *3.4 Analysis of Physical Composition*

The presence of clay is higher in the Gullies do Barreiro and the Retreat, being 46.7% and 43.2% respectively (Figure 5). Gullie da Vendinha has a lower percentage of silt, but the highest sand. Samples of Gullie and Vendinha, including that of the lower third of Gullie do Capim, were the ones that stood out due to the high percentage of sand and low percentage of clay. The samples with the highest sand content belong to the Franco Argilo Arenoso textural class. The others are represented by the textural class clay, that is, it has a moderate amount of clay, considering in this case as non-clayey and non-sandy soil.

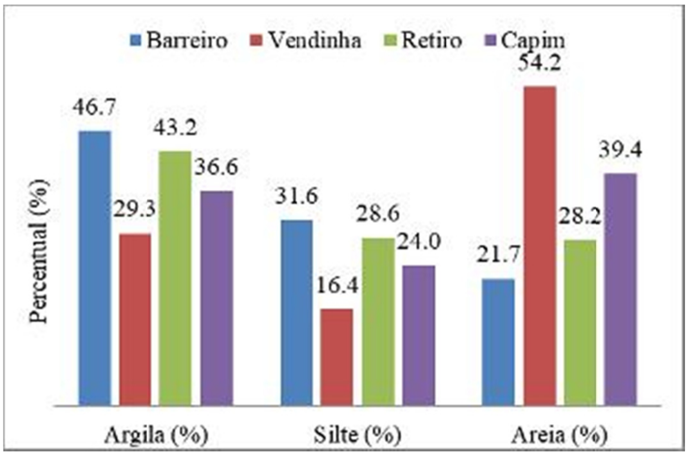


Figure 5. Average composition of the soils of the Barreiro, Vendinha, Retiro and Capim soils in the Ribeirão Serra basin, Morrinhos, Goiás, Brazil

### *3.5 Multivariate Analysis*

Figure 6 presents the results of the multivariate analysis according to the model generated from the physical-chemical analysis of the soils of the four gullies. The main components 1 and 2, together explained 73.8% of the total variance of the soil profile that differentiates the characteristics of the gullies, considering the joint analysis. It is possible to verify that the model differentiates the Barreiro, Vendinha and Capim gullies, while there are similarities between the gull of the Retreat with the gullies Vendinha and Capim (Figure 6b). According to the multivariate analysis, we can consider that the differences between the gullies, through the chemical and physical parameters, are considered for grouping of areas and conditions of formation or advancement of gullies. It also highlights that practically all the gullies are in areas surrounded by pastures, or anthropized in different levels. According to Marques et al. (2014), the gullies should be considered because of their specific characteristics, both training and recovery, the authors add that anthropization enhances the formation of gullies

The elements with higher weights, to differentiate the gullies, in order of high importance highlight the elements of Potassium (K) and Organic Matter (OM), followed by medium importance, the elements Ca (Calcium), CTC (Cation exchange capacity ), Sat Base (Base Saturation) and H (Hydrogen), and finally the lower weight elements (Figure 6b). In the order of weight of the elements, the chemical factors are more important than the physical ones (clay, silt and sand), noting that not only the soil type can determine the erodibility process, it also considers the use and soil management may interfere with the anchorage of the gull. Figure 6d shows the cross-validation (10-fold) performance model of PLS-DA elements considering that the model presents good accuracy and performance (R2), resulting in average overall performance (Q2).

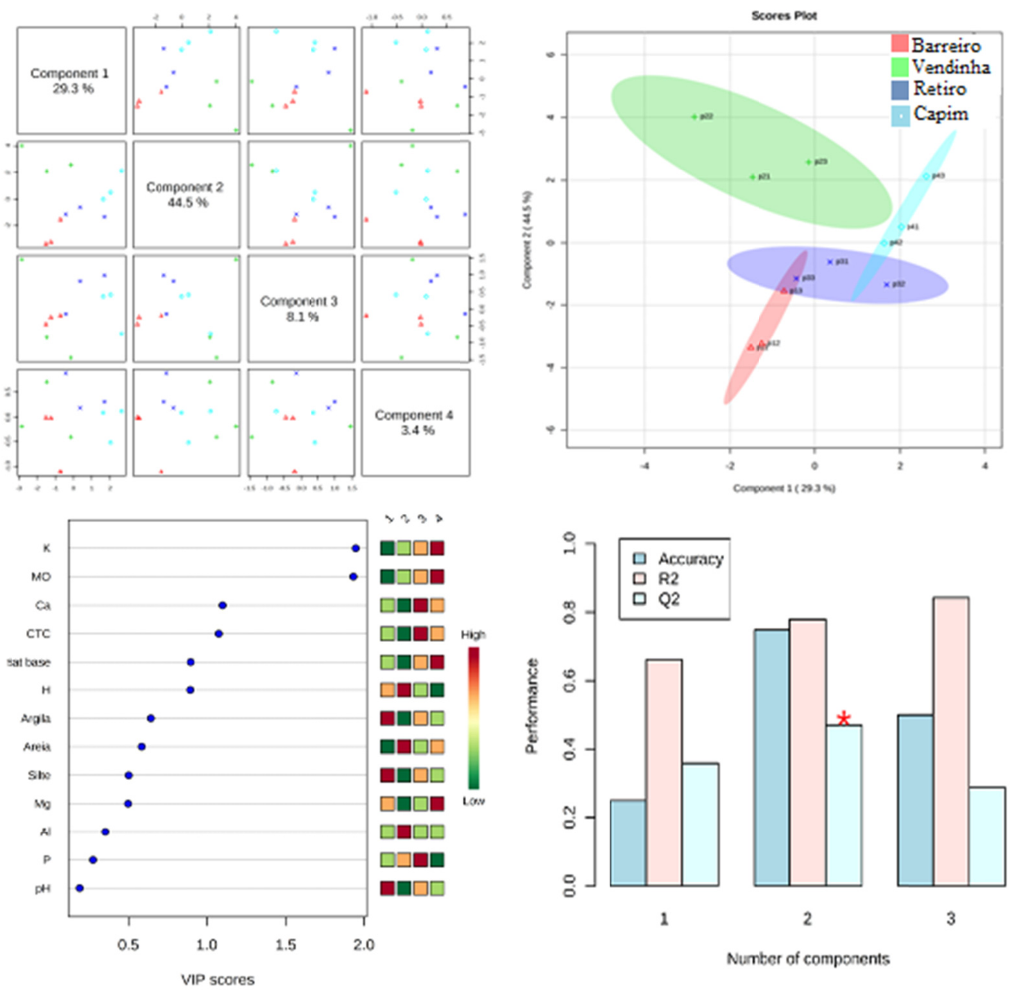


Figure 6. Components of the multivariate analysis PLS-DA, with chemical and physical data set of the gullie soils 1: Barreiro, 2: Vendinha, 3: Retreat and 4: Grass of the Ribeirão Serra sub-basin, Morrinhos municipality, Goias, Brazil

*Note*. * at where; K (Potassium), MO (Organic Matter), Ca (Calcium), CTC (Cation Exchange Capacity), Sat Base, H (Hydrogen), Mg, Al phosphorus), pH (hydrogenation potential), sand, silt and clay (physical factors of the soil).

There is a high degree of anthropization with the use of pasture cultivated around the four gullies studied. The Vendor voorah has a higher sand composition and greater risk of expansion through erosive instabilities. The most stable gullies with presence of vegetation in their interior and low levels of sand in the physical composition of the soil are the one of the Retreat and the one of the Capim. The superficial layers of the soils of the gullies present a higher concentration of organic matter. According to the multivariate analysis the gullies Barreiro, Vendinha and Capim, are different, while it resembles the gull of the Retreat with the gullies Vendinha and Capim. The chemical elements present greater weight than physical ones, in the separation of the gullies through the multivariate model.

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