# Erosion inventory in the region of São Sedro and Barra Bonita cities, State of São Paulo, Brazil

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**Abstract:** The inventory and assessment of changes in the degree of the erosion in the Sao Pedro and Barra Bonita region, in the state of Sao Paulo, Brazil is part of environmental management study for the region. Geomorphologically, this region is characterized by 3 units, namely: Planalto Ocidental (altitudes around 1000m), Cuestas Basalticas (altitudes varying from 1000 m to 650 m) and Depressão Periférica (altitudes between 650 to 550m). These geomorphologic units respectively consist of sedimentary rocks (sandstones, siltstones, and claystones), igneous and sedimentary rocks (basalts and cemented sandstones) and sandstones of the Pirambóia Formation. The hydrographic basins occupy two well determined levels of altitude because the upstream is located in the Planalto Ocidental and downstream portion is in the Depressão Periférica unit. The sediments produced in each basin are transported to the reservoir of the Barra Bonita Dam, which is used to generate energy. The inventory was carried out at scale of 1:25,000 by means of analysis of aerial photographs of different dates and by fieldwork. The erosional features were classified as gullies with varied geometry and dimensions, and ravines. The drainage channels display evidence of stream bank and sheet erosion that occur in the areas prepared for plantation. Most erosion features are developed between November and March, which is the period characterized by intense rainfall.

**Résumé:** Le inventaire et l'évaluation de l'évolution du degré de l'érosion dans la région de São Pedro et de Barra Bonita, dans l'état de São Paulo, Brésil fait partie d'une étude régionale pour la gestion environnementale. La géomorphologie, des cette région est caractérisée par 3 unités dénommées: Planalto Ocidental (altitudes autour de 1000m), Cuestas Basálticas (altitudes changeant de 1000 m à 650 m) et Depressão Periférica (altitudes 650 à 550m). Ces unités géomorphologiques se composent des roches sédimentaires (grès, siltstones, claystones), les roches ignées et sédimentaires (des basaltes et des grès cimentés) et les grès de la formation de Piramboia, respectivement. Les bassins hydrographiques présentent deux niveaux d'altitude bien déterminés parce que l'ascendant est situé dans le Planalto Ocidental et la partie descendant est dans l'unité Depressão Periferica. Les sédiments qu' ont été produit en chaque bassin ont été transportés au réservoir du barrage de Barra Bonita qui est utilisé pour produire de l'énergie. Le inventaire a été effectué à la échelle 1:25.000 au moyen d'analyse des photographies aériennes de différentes dates et par des travaux sur le terrain. Les erosion ont été classifiés comme ravinée avec des géométrie et des dimensions, diverses. Il y a aussi evidence actuelle de l'érosion de banque de lleuve, et l'érosion de feuille se produit dans les secteurs préparés pour la plantation. La plupart de l'érosion est développées entre novembre et mars, qui est la période caractérisée par des précipitations intenses.

**Keywords:** soil erosion, land use, environmental impact,

## INTRODUCTION

Among the different sources of land degradation erosion processes have great importance as indicated by the large number of studies undertaken world-wide. The problems due to these processes have increased in the last fifty years due to intense human interference and deforestation to provide agricultural land. Many inventory studies with differing goals and results are reported but because predominantly only the location of features is recorded without information about their characteristics, these studies are of limited use.

In Brazil erosion is a very common induced or natural process that has economic and social consequences, including serious financial losses. The state of São Paulo, in the southeast region of Brazil, has around 50,000 gully erosion features distributed on different sandy geological units. In the central area, the Piracicaba river basin is greatly affected by erosion process. This paper describes a study of an area, see Figure 2, of 600 $km^2$ to the north of a reservoir consisting of 7 sub-basins (Samanbaia, Meio, Vermelho, Barra, Tabaranas, Bonito and Serelepe), all tributaries of the Piracicaba River. The main point of this paper is to present some of the results obtained by the use of datasheets developed to evaluate erosion features related to sheet, rill, ravine, gully, stream bank and piping processes in the Barra basin.

## BACKGROUND

It is possible find in the literature a thousand of papers about erosion studies and some of these refer to inventories but it is very unusual to find datasheets used in these studies. According to Morgan (1996) and also Perrens and Trustrum (1984), erosion inventories are fundamental documents for adequate territorial and environmental management of areas affected by erosion, as shown in Figure 1. Natural process inventory maps delineate the distribution of one or more geomorphological processes, such as flooding, erosion and landsliding. Such processes can be shown by polygons, feature outlines, linear symbols and/or point symbols. Erosion inventory maps are produced for a variety of purposes, including: delineation of different types or sizes of erosion features; to distinguish inactive, active, or recently active, erosion features from those which are dormant; to document erosional damage incurred in a region from a specific event; to guide research or mitigation spending within a region; and/or to calibrate and provide details to other types of terrain maps. Erosion feature density maps, an extension of erosion inventory maps, use contours to join areas with equal densities of erosion features (isopleths), and are useful in areas that contain a relatively large number of relatively small erosion features. In some countries attempts are being made to establish national erosion features inventory mapping programmes, accompanied by a data bases.

Recent examples of relevant studies include those developed by Lewis et al. (2000) for water quality management, Pacific Watershed Associates (2003) who developed inventory results, erosion control and an erosion prevention plan for 36km of haul road, in California, USA. Trinity County Planning Department - Natural Resources Division (1999) conducted a County Roads Erosion Inventory in various counties also in the state of California. The sites inventoried were those with the potential to deliver sediment to streams, resulting in damage to fishery resources and/or water quality, U.S. Department of Agriculture – USDA (2001) prepared a Field Procedures Guide for the Headcut Erodibility Index as part of the National Dams Engineering Handbook. Another example is Øygarden & Grønlund's (2005) paper on Indicators for soil erosion in Norway with different aspects related to erosion processes, and finally, Larson et al. (2001) carried out a study into problems due to agricultural erosion in the State of Minnesota, USA.

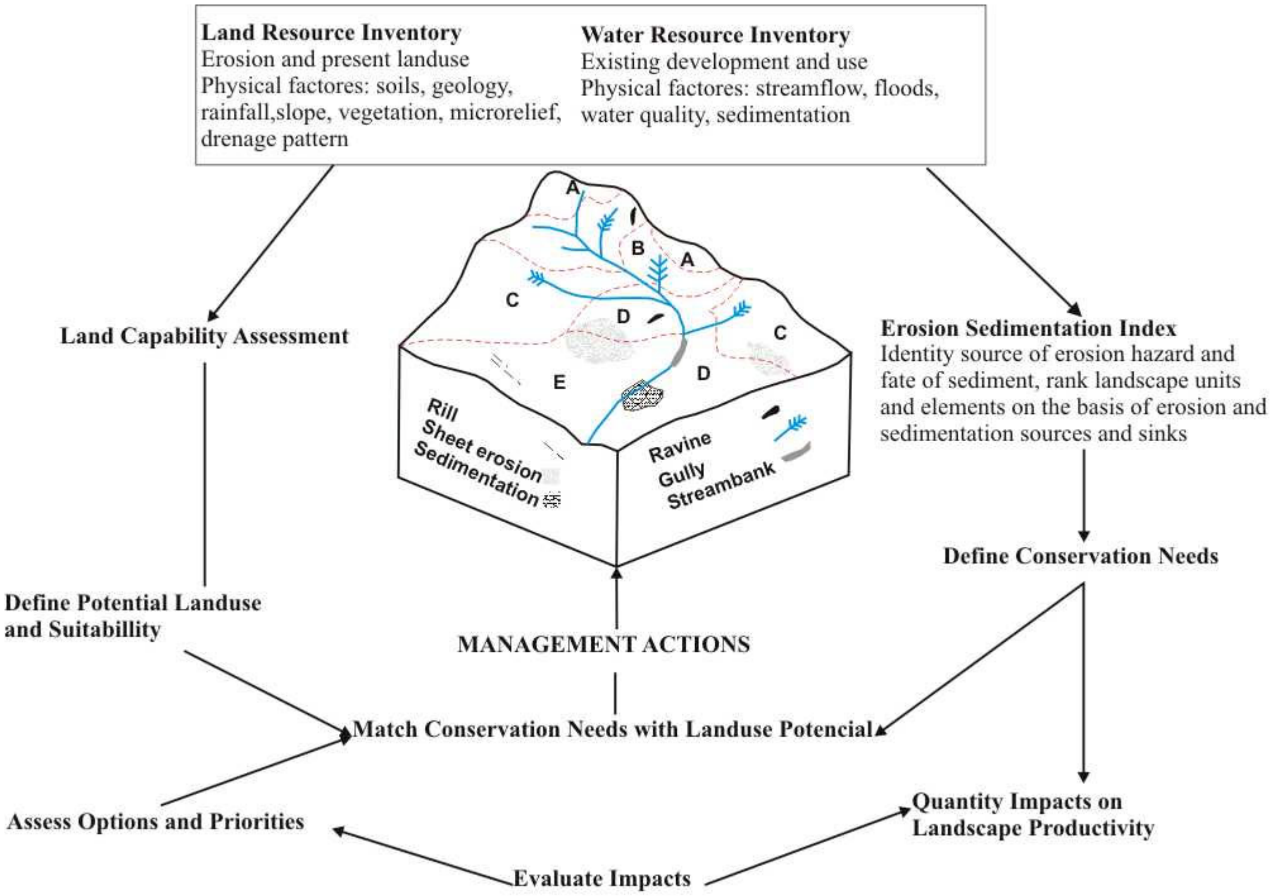


**Figure 1.** Sequence of events in planning a soil conservation strategy (modified from Perrens and Trustrum, 1984 after Morgan, 1996)

## BASIC GENERAL CHARACTERISTICS of study area

The Barra watershed was selected for the initial study because is representative of the general characteristics of the studied region. .As shown in Figure 2, this is located between latitudes 7488 and 7516 km N and longitudes 192 and 204 km E (UTM zone 23) and 784 and 808 Km E (UTM zone 22). It covers 600 $km^2$ comprising the municipalities of São Pedro and Santa Maria da Serra, Sao Paulo State. The climate is classified as dry with maximum and minimum average temperature 28° C and 15° C, respectively and an annual average pluviosity of 1175 mm. The monthly average varies from 20 to 40 mm for dry, and 140 to 220 mm for wet periods. Due to scarps there are strong orographic rains. Geologically, the area is located in the border of the Paraná sedimentary basin, which is underlain by sandstones, siltstones and claystones of the Itaqueri Formation (K), Basalts of Serra Geral Formation (JK), strongly cemented aeolian sandstones of the Botucatu Formation (JK) and cemented sandstones of the Pirambóia Formation (TrJ). The relief is divided into 3 very well-defined zones: Highland (Planalto occidental) with altitudes higher than

900m where the geological material is predominantly of the Itaqueri and Serra Geral Formations; very steep slope-scarps (Cuestas Basalticas) with inclination higher than 75º and altitudes varying from 500 to 900m with basalts and sandstones of Serra Geral and Botucatu Formations; and an undulating zone (Depressão periférica) of gentle slopes with rock substrate consisting of sandstones of the Pirambóia Formation. The unconsolidated materials are predominantly sandy transported and residual deposits dirived from sandstones, which occur in more than 75% of the region, with thicknesses ranging from 1 to 30m. Their hydraulic conductivity varies between $10^{-5}$ and $10^{-6}$ m/s and their erodibility index according several methods is high.

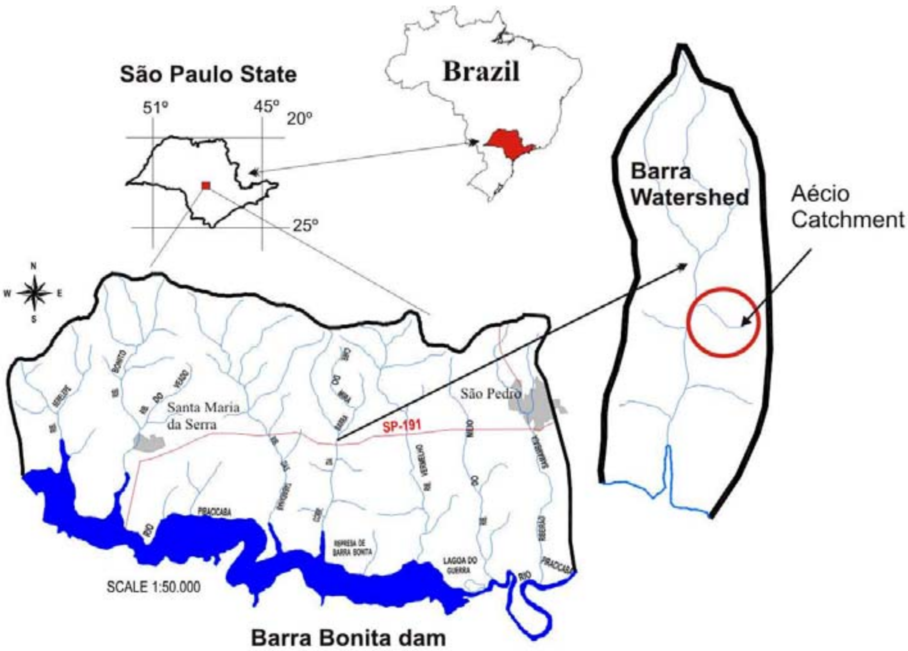


**Figure 2** . Location map of the studied area, to the north of the Barra Bonita Reservoir. Scale should be shown by a scale bar

The main land uses of the area are sugar cane and orange plantations, pastures and eucalyptus reforestation. The natural vegetation in the scarps areas is preserved because there are tourist activities related to waterfalls and watersports.

# METHODOLOGY

The works were accomplished to 5 phases as follows:

## *Development of data sheets*

The study began with bibliographic review of research into the concepts of the erosion process and inventories. This enabled adoption of the most appropriate concepts and to get a general view about inventory and the character of the erosional feature being studies. For the purposes of the study the definitions for **natural erosive** processes adopted by SSSA (2005) where as , and **accelerated erosion** as the erosion in excess of natural rates, usually as a result of anthropogenic activities. The terms for the erosion types were defined SSSA(2005) as follows:

**Gully erosion**: The erosion process whereby water accumulates and often recurs in narrow channels and, over short periods, removes the soil from this narrow area to considerable depths, often defined for agricultural land in terms of channels too deep to easily ameliorate with ordinary farm tillage equipment, typically ranging from 0.5m to as much as 25 to 30m deep.

**Rill erosion**: An erosion process on sloping fields in which numerous and randomly occurring small channels up to several centimetres deep are formed; occurs mainly on recently cultivated soils.

**Sheet erosion**: The removal of a relatively uniform thin layer of soil from the land surface by rainfall and largely unchanneled surface runoff (sheet flow).

**Soil piping or tunnelling**: Accelerated erosion that results in subterranean voids and tunnels.

**Streambank erosion**: is the direct removal of banks and beds by flowing water. Typically, it occurs during periods of high stream flow. It is sometimes confused with gully erosion as it has similarities in seasonal or ephemeral streams.

For the ravine and slope-road erosion, the following terms were defined:

**Ravine:** an erosional feature intermediate in scale between a rill and a gully.
**Slope-road erosion:** The erosion processes, including rills, gullies and ravines, that occur on embankments or natural slopes on, access roads, roadsides and roadways.

The information obtained in the first phase was used to improve the datasheets (Tables 1 to 6) for sheet, rill/ ravines, gully, stream bank, piping and slope-road processes. Several aspects of the environment and erosion processes were recorded, including: identification, general characteristics, morphology, morphometry, geological materials, degree of development, activity, severity, hydrological and hydrogeological characteristics, pre-disposition and triggering aspects, types and efficiency of the control and rehabilitation measures, and environmental elements affected by erosion process. As Table 1 to 6 show, a number of pieces of qualitative and quantitative information was recorded for each topic.

## *Application to Barra Watershed*

After the datasheet had been modified the basic flow chart (Figure 3) was developed to ensure the data sheets were correctly and accurately completed. In the forth phase the methodology was applied to the Barra Basin in combination with photointerpretation and desk studies. In the final phase of the work

The data recorded on the data sheets were analysed to evaluate the efficiency of proposed datasheet and also provide data about the conditions of the erosional features in the Barra watershed.

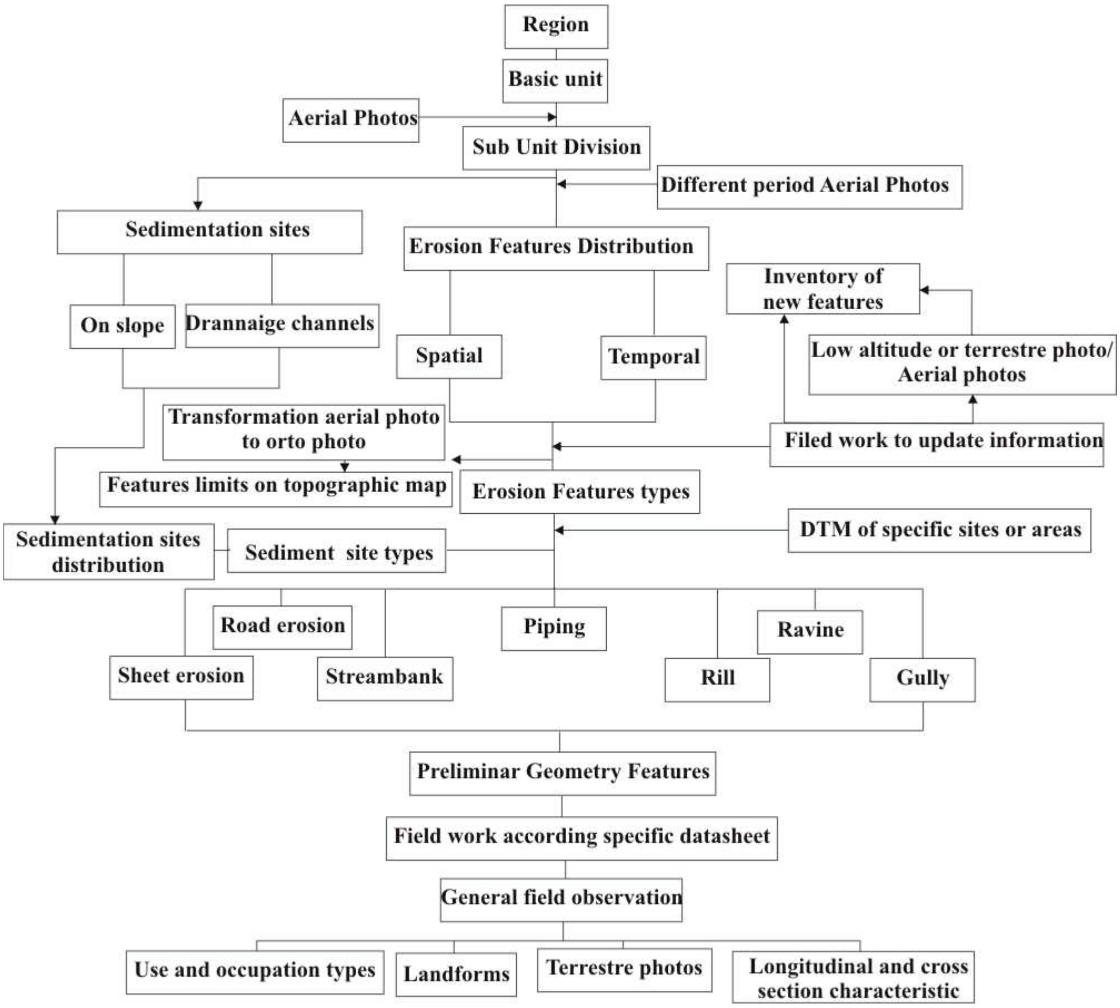


**Figure 3.** Flowchart showing the methodological stages of the work.

**Table 1.** Stream bank inventory datasheet

<table>
<tr><td colspan="12">STREAM BANK INVENTORY</td></tr>
<tr><td colspan="6">1. Identification and location</td><td colspan="6">Feature Number</td></tr>
<tr><td colspan="2">Site Number:<br>Photo Numbers:</td><td colspan="3">Date:<br>Map Sheet Number:<br>River:</td><td colspan="4">GPS Coordinates:_______________ N<br>_______________ E</td><td colspan="3">Topographic sheet:<br><br>Photos:</td></tr>
<tr><td colspan="12">2 General Characteristics</td></tr>
<tr><td colspan="3">Watershed</td><td colspan="3">Sediment Transport</td><td colspan="6">Frequency (Nº/Km)</td></tr>
<tr><td colspan="3">Landforms:<br>Terrace ( ) Slope ( )</td><td colspan="3">Vegetation:<br>( ) Riparian vegetation</td><td colspan="6">Uses:<br>( ) water discharge pipeline ( ) sand/aggregate extraction ( ) other</td></tr>
<tr><td colspan="12">3. Morphology</td></tr>
<tr><td colspan="6">Bank<br>Type ( ) continue ( ) rectilinear ( ) concave<br>Vertical and longitudinal shape</td><td colspan="6">Feature<br>( ) diverse points of the area</td></tr>
<tr><td colspan="12">4. Morphometry</td></tr>
<tr><td colspan="9">Bank</td><td colspan="3">Feature</td></tr>
<tr><td>Length (m)</td><td>Height (m)</td><td colspan="2">Wide (m)</td><td colspan="2">declivity</td><td colspan="3">Movement material volume ($m^3$)</td><td colspan="3">Amount of erosion and slope ratio<br>Side slope of bank (circle one)<br>Vertical 1:1 2:1 3:1 4:1 or flatter</td></tr>
<tr><td colspan="12">5. Geological Material</td></tr>
<tr><td colspan="3">Profile (thickness , spatial distribution and heterogeneity)</td><td colspan="2">Organic material layer<br>( ) presence ( ) no presence</td><td colspan="2">Clay mineral type</td><td colspan="3">Soil texture<br>( ) Sand ( ) Clay ( ) Silt ( ) Gravel<br>( ) Other</td><td colspan="2">Origin<br>( ) Transported<br>( ) Residual</td></tr>
<tr><td colspan="4">6. Evolution stage<br>( ) Early ( ) Intermediate ( ) Old</td><td colspan="3">7. Activity Degree<br>( ) Active ( ) Dormant ( ) Stable</td><td colspan="5">8. Severity degree<br>( ) Minor ( ) Moderate ( ) Severe</td></tr>
<tr><td colspan="12">9. Water condition ( ) Temporary ground water flow - describe</td></tr>
<tr><td colspan="12">10. River Conditions: ( ) Approximate width of river, ( ) Depth of rie:_______ at _____ from the bank, Current ( )Slow ( ) Moderate ( ) Fast</td></tr>
<tr><td colspan="6">12. Potential unfavourable and trigger attributes<br>( ) land use ( ) Peaking ( ) Surface water entering<br>( ) Bend or obstruction in river ( ) Bank seepage<br>( ) Other</td><td colspan="6">13. Bank Condition<br>( ) Toe is undercutting ( ) Toe is stable, upper bank eroding<br>( ) Toe and upper bank eroding<br>( ) Percent of vegetative cover on bank (0-10%, 10-50%, 50-100%)<br>( ) Other (describe): ________________________________</td></tr>
<tr><td colspan="12">14. Progression ( ) continua ( ) intermittent</td></tr>
<tr><td colspan="12">15. Control measures<br>( ) Rock rip-Rap ( ) Tree revetment ( ) Bank Sloping ( ) Stairways ( ) Bank seeding or planting ( ) Fencing ( ) Other</td></tr>
<tr><td colspan="12">16. Affected element ( ) Residence, ( ) Road/ Way, ( ) Bridges, ( ) water supply, ( ) silting, ( ) other</td></tr>
<tr><td colspan="12">17. Scheme</td></tr>
<tr><td colspan="12"></td></tr>
</table>

**Table 2.** Slope road erosion inventory datasheet

| SLOPE ROAD EROSION INVENTORY | | | |
|---|---|---|---|
| **1. Identification and location** | | | **Feature Number** |
| Site Number:<br>Photo Numbers: | Date:<br>Map Sheet Number:<br>Road: | GPS Coordinates: _______________ N<br>_______________ E | Topographic sheet:<br>Photos: |
| **2 General Characteristics** **Watershed** | **Road type:** | **Frequency (Nº/Km)** | |
| **3. Slope Morphology**<br>**Landforms:**<br>***Natural slope shape***<br>Concave/Concave ( )<br>Concave/Convex ( )<br>Concave/Linear ( )<br>Convex/ Concave ( ) | Convex/ Convex ( )<br>Convex/ Linear ( )<br>Linear/ Concave ( )<br>Linear/ Convex ( )<br>Linear/ Linear ( ) | Flood Plain ( )<br>Scarp ( )<br>Plateau ( ) | **Types of feature erosion**<br>( )sheet<br>( ) Rill/Ravine<br>( ) Gully<br>( ) piping or tunneling<br>**Datasheet nº** |
| **4. Slope Morphometry** | | | |
| **Natural**<br>Length (m) Height (m) wide (m) Declivity | | **Man-made**<br>Length (m) Height (m) wide (m) Declivity | |
| **5. Geological Material** | | | |
| Profile(thickness , spatial distribution and heterogeneity ) | Organic material layer | Clay mineral type | Compaction degree |
| **6. Evolution stage**<br>( ) Early ( ) Intermediate ( ) Old | **7. Activity Degree**<br>( ) Active ( ) Dormant( ) Stable | **8. Severity degree**<br>( ) Minor ( ) Moderate ( ) Severe | |
| **8. Water condition** ( ) Surface water drainage system ( ) temporary ground water flow | | | |
| **9. Potential unfavourable and trigger attributes** | | | |
| **10. Progression-** describe ( ) Low potential ( ) High potential | | | |
| **12. Control measures** ( ) Reforestation , ( ) Rock rip-Rap, ( ) anchor, ( ) Other: --------- | | | |
| **13. Affected element** ( ) Road/ Way, ( ) Bridges ( ) Other: --------- | | | |
| **14. Scheme** | | | |
| | | | |

**Table 3.** Rill and Ravine inventory datasheet

| RILL/RAVINE INVENTORY | | | | | |
|---|---|---|---|---|---|
| **1. Identification and location** | | | | | **Feature Number** |
| Site Number:<br>Photo Numbers: | Date:<br>Map Sheet Number: | GPS Coordinates: _______________ N<br>_______________ E | | | Topographic sheet:<br>Photos: |
| **2 General Characteristics**<br>**Watershed**<br>**Sediment Deposits**<br>**Frequency (Nº/ha)** | | **Uses:** ( ) Urban ( ) Pasture<br>Agriculture ( ) Terraces ( ) Without terraces<br>Roads ( ) Pavement ( ) Not pavement road<br>( ) Forest ( ) Natural conditions ------------------ | | | |
| **3. Morphology** | | | | | |
| **Slope**<br>**Landforms:**<br>***Natural slope shape***<br>Concave/Concave ( )<br>Concave/Convex ( )<br>Concave/Linear ( ) | Convex/ Concave ( )Convex/ Convex ( )<br>Convex/ Linear ( )<br>Linear/ Concave ( )<br>Linear/ Convex ( )<br>Linear/ Linear ( ) | Flood Plain ( )<br>Scarp ( )<br>Plateau ( ) | **Feature**<br>Spatial distribution<br>Sinuosity<br>Talweg gradient<br>Cross section shape | | |
| **4. Morphometry** | | | | | |
| **Slope**<br>Length (m) Wide (m) Depth (m) Area ($m^2$) Volume($m^3$) Declivity | | | **Feature**<br>Length (m) Wide (m) Depth (m) Area ($m^2$) Volume($m^3$) Declivity | | |
| **5. Geological Material** | | | | | |
| Profile (thickness , spatial distribution and heterogeneity) | Soil structure | Origin<br>( ) Transported<br>( ) Residual | Compaction Degree | Texture<br>( ) Sand ( ) Clay ( ) Silt<br>( ) Gravel( ) Other | Clay mineral type |
| **6. Evolution stage**<br>( ) Early ( ) Intermediate ( ) Old | | **7. Activity Degree**<br>( ) Active ( ) Dormant ( ) Stable | | **8. Severity degree**<br>( ) Minor ( ) Moderate ( ) Severe | |
| **8. Water condition** ( ) Temporary ground water flow | | | | | |
| **9. Potential unfavourable and trigger attributes** | | | | | |
| **Natural factors**<br>( ) heavy rains on weak soil ( ) steep slopes<br>( ) vegetation depleted by drought<br>sudden climate change ( ) rainfall ( ) drought ( ) | | | **human-induced factors**<br>( ) change of land (deforestation) ( ) intensive farming<br>( ) housing development ( ) road construction | | |
| **10. Progression** ( ) Low potential ( ) High potential | | | | | |
| **12. Control measures** ( ) Drainage system, ( ) Reforestation, ( ) Change the geometric conditions, ( ) change the use practices, ( ) Other: --------- | | | | | |
| **13. Affected element** ( ) Road/ Way, ( ) Cultured Area, ( ) quality of the water, ( ) Other------------------------ | | | | | |
| **14. Scheme** | | | | | |
| | | | | | |

**Table 4.** Sheet erosion inventory datasheet

| **SHEET EROSION INVENTORY** | | | |
|---|---|---|---|
| **1. Identification and location** | | | **Feature Number** |
| Site Number:<br>Photo Numbers: | Date:<br>Map Sheet Number: | GPS Coordinates:_______________ N<br>_______________ E | Topographic sheet:<br>Photos: |
| **2 General Characteristics**<br>**Watershed**<br>**Sediment Deposits** | **Uses:** ( ) Urban ( ) Pasture<br>Agriculture ( ) Terraces ( ) Without terraces<br>Roads ( ) Pavement ( ) Not pavement road<br>( ) Forest ( ) Natural conditions ------------------- | | |
| **3. Morphology** | | | |
| **Slope**<br>**Landforms:**<br>***Natural slope shape***<br>Concave/Concave ( )<br>Concave/Convex ( ) | Concave/Linear ( )<br>Convex/ Concave ( )<br>Convex/ Convex ( )<br>Convex/ Linear ( )<br>Linear/ Concave ( ) | Linear/ Convex ( )<br>Linear/ Linear ( )<br>Flood Plain ( )<br>Scarp ( )<br>Plateau ( ) | **Feature**<br>Sediment accumulation zone<br>Sheet location en slope |
| **4. Morphometry** | | | |
| **Slope**<br>Length (m) Wide (m) Depth (m) Area ($m^2$) Declivity | | **Feature**<br>Length (m) Wide (m) Depth (m) Area ($m^2$) Volume($m^3$)<br>Declivity | |

| **5. Geology Material** | | | | | **6. Severity degree** |
|---|---|---|---|---|---|
| Profile (describe soil) | Organic material layer | Texture soil<br>( ) Sand ( ) Clay ( ) Silt<br>( ) Gravel ( ) Other | Clay mineral type | Compaction degree | ( ) Minor( ) Moderate ( ) Severe |

| | |
|---|---|
| **7. Water condition** ( ) Temporary ground water flow - describe | |
| **8. Potential unfavourable and trigger attributes** | |
| **Natural factors**<br>( ) heavy rains on weak soil ( ) steep slopes<br>( ) vegetation depleted by drought<br>sudden climate change ( ) rainfall ( ) drought ( ) | **human-induced factors**<br>( ) change of land (deforestation): ( ) intensive farming<br>( ) housing development ( ) road construction<br>( ) Kind of pasture |
| **9. Progression** ( ) Low potential ( ) High potential | |
| **10. Control measures** ( ) ( ) Reforestation , ( ) Other: **---------** | |
| **11. Affected element** ( ) Cultured Area, ( ) Other: **---------** | |
| **12. Scheme** | |
| | |

**Table 5.** Gully inventory datasheet

**GULLY INVENTORY**

| **1. Identification and location** | | | **Feature Number** |
|---|---|---|---|
| Site Number:<br>Photo Numbers: | Date:<br>Map Sheet Number: | GPS Coordinates: _______________ N<br>_______________ E | Topographic sheet:<br>Photos: |

| **2 General Characteristics** | |
|---|---|
| **Watershed**<br>**Type**<br>( ) slope ( ) upstream portion ( ) deep of valley<br>**Order drainage channel** | **Uses:** ( ) Urban ( ) Pasture<br>Agriculture ( ) Terraces ( ) Without terraces<br>Roads ( ) Pavement ( ) Not pavement road<br>( ) Forest ( ) Natural conditions ------------------- |

| **3. Morphology** | | | | | |
|---|---|---|---|---|---|
| **Slope**<br>**Landforms:**<br>***Natural slope shape***<br>Concave/Concave ( )<br>Concave/Convex ( )<br>Concave/Linear ( ) | Convex/ Concave ( )<br>Convex/ Convex ( )<br>Convex/ Linear ( )<br>Linear/ Concave ( )<br>Linear/ Convex ( )<br>Linear/ Linear ( ) | Flood Plain ( )<br>Scarp ( )<br>Plateau ( ) | **Feature**<br>Topography position<br>( ) Superior part<br>( )Intermediary part<br>( ) Inferior part | 1-Branch<br>2-Angularity<br>3-Baseline gradient<br>4-Wall heterogeneity degree<br>5- Cross section shape | Position to the drainage channel<br>( ) inclined<br>( ) orthogonal<br>( ) Parallel |

| **4. Morphometry** | | |
|---|---|---|
| **Slope** | | **Feature** |
| **Natural**<br>Length (m) Height (m)<br>wide (m) Declivity | **Man-made**<br>Length (m) Height (m)<br>wide (m) Declivity | Length (m) Wide (m) Depth (m) Uniformity Area ($m^2$)<br>Volume ($m^3$)<br>Different baseline gradient |

| **5. Geology Material** | | | | | |
|---|---|---|---|---|---|
| Profile (thickness , spatial distribution and heterogeneity ) | Texture soil<br>( ) Sand ( ) Clay ( ) Silt<br>( ) Gravel ( ) Other | Origin<br>( ) Transported<br>( ) Residual | Compaction Degree | Clay mineral type | Soil structure |

| **6. Evolution stage** | **7. Activity Degree** | **8. Severity degree** |
|---|---|---|
| ( ) Early ( ) Intermediate ( ) Old | ( ) Active ( ) Dormant ( ) Stable | ( ) Minor ( ) Moderate ( ) Severe |

| **8. Water condition** |
|---|
| ( ) Water flow presence ( ) Piping presence ( ) Temporary ground water flow presence ( ) ground water flow ( ) Temporary water flow |

| **9. Potential unfavorable and trigger attributes** |
|---|
| ( ) Increase in flow of surface (or subsurface) water ( ) Decrease of soils resistance to erosion ( ) Sloughing and mining at the bottom of the gully |

| **10. Progression**<br>( ) Length direction (upstream and downstream) ( ) Lateral ( ) Depth ( ) All | Energy base level of the area |
|---|---|
| **12. Control measures** ( ) Terracing , ( ) Lined channels, ( ) Drop structures/Grade Control Structures, ( ) Cross-section of a typical grassed waterway ( ) Grassed waterways, ( ) Cross section of a pipe drop structure ( ) Other: --------- | |
| Implanted (Efficiency result) | Proposed |
| **13. Affected element** ( ) Residence, ( ) Road/ Way, ( ) Bridges ( ) Cultured Area, ( ) Other: --------- | |
| **14. Scheme** | |

**Table 6.** Piping erosion inventory datasheet

| PIPING EROSION INVENTORY | | | |
|---|---|---|---|
| **1. Identification and location** | | | **Feature Number** |
| Site Number:<br>Photo Numbers: | Date:<br>Map Sheet Number: | GPS Coordinates: _______________ N<br>_______________ E | Topographic sheet:<br>Photos: |
| **2 General Characteristics** | | | |
| **Watershed** | **Altitude:** | **Frequency (Nº/ha)** | |
| **Landforms:** ( ) closed valley ( ) open valley | | **Uses:** ( ) water discharge pipeline ( ) aggregate extraction ( ) other | |
| **3. Morphology Feature** | | | |
| F  | | Cemented Wall or not | To the terrain surface |
| **4. Morphometry Feature** | Diameter (m) | Depth (m) | |
| **5. Geological Material** | **6. Evolution stage** | **7. Activity Degree** | **8. Severity degree** |
| Associated<br>( ) soil type<br>( ) geological structure<br>( ) Clay mineral type<br>( )Other | ( ) Early<br>( ) Intermediate<br>( ) Old | ( ) Active<br>( ) Dormant<br>( ) Stable | ( ) Minor<br>( ) Moderate<br>( ) Severe |
| **9. Water condition** ( ) Water flow ( ) temporary water flow presence ( ) Dry | | | |
| **10. Potential unfavourable and trigger attributes** ( ) soil type ( ) discontinuity | | | |
| **11. Progression-** describe ( ) Low potential ( ) High potential | | | |
| **12. Control measures** ( )surface drainage system , ( ) subsurface drainage system, ( ) Other: --------- | | | |
| **13. Scheme** | | | |
| | | | |

# TYPES OF EROSIONAL PROCESSES

All erosional process types were found to be present. The Aécio catchment (see Figure 2), which is a first order tributary according to the Sthraller classification, has been chosen here as an example of the results. This small area is affected for sheet, rill, ravine, gully and stream bank erosion processes.

## *Sheet*

This process affects pasture land and orange plantations, (Figure 4) in the space between 2 terraces (50m) with declivity varying from 5 to 10%. The ground consists of unconsolidated sandy residual soil that has a high erodibility index. The terraces are not an effective means of controlling the erosion because the high rugosity of the micro relief (Figure 5). This process has affected pasture quality and the susceptibility of the terraces to sedimentation.

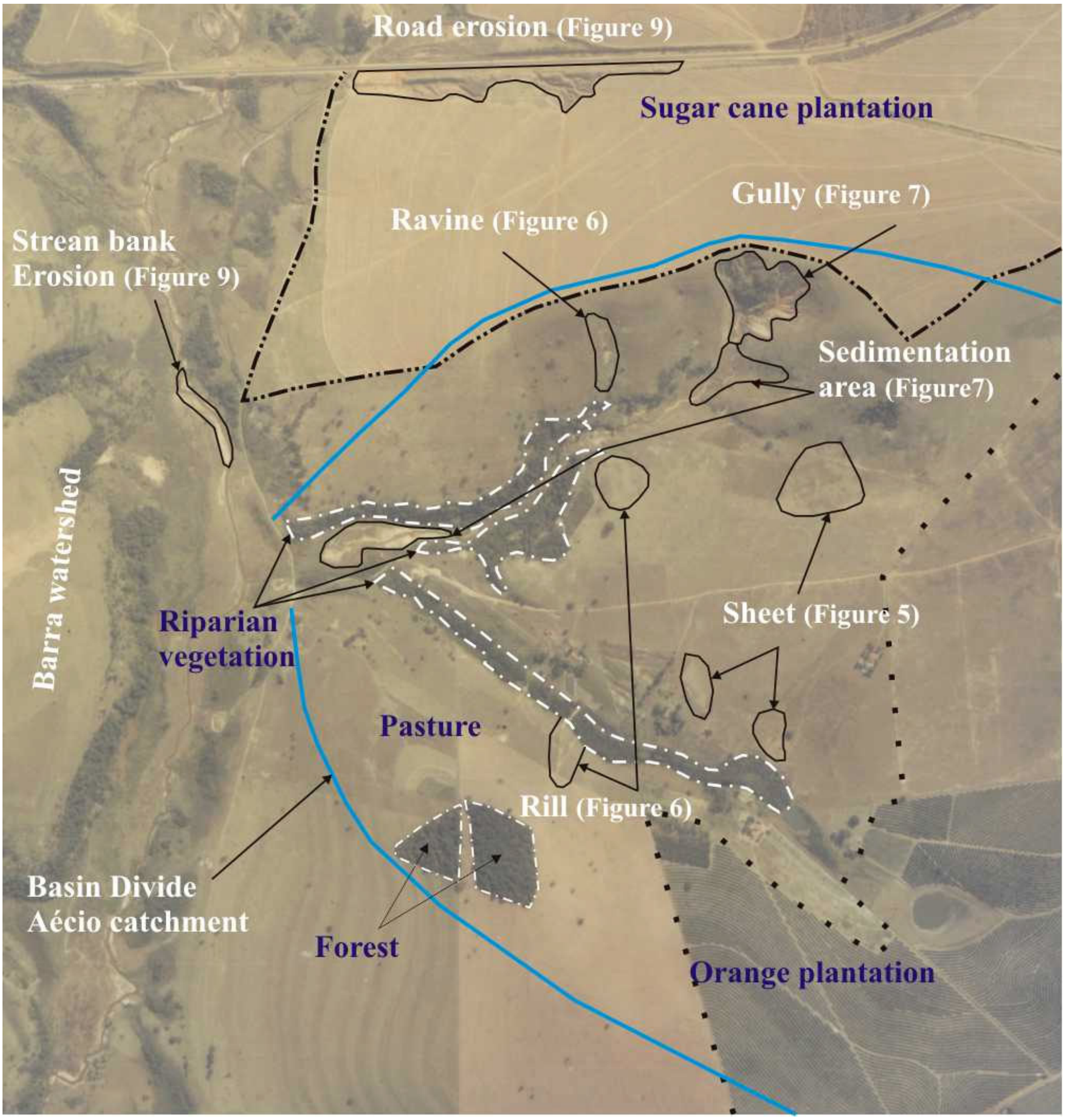


**Figure 4.** Aécio catchment with erosion process features and land uses (Aerial photography 2000 at scale 1:30,000).

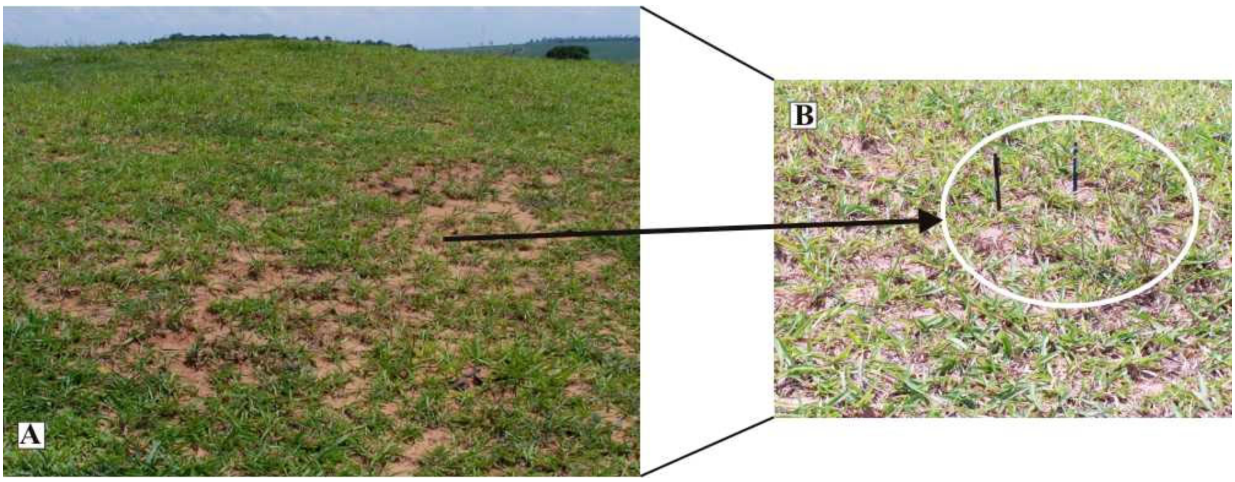


**Figure 5.** (A) Sheet erosion and (B) Detail of part of area A.

## Rill

This feature occurs on convex/linear slope, in pasture and orange plantation areas (Figures 4 to 6), at a frequency of 6 features per 20m, where each feature is about 30cm wide, 20 cm deep and 500m long. They have low sinuosity, annual reactivation, low severity, low progress potential. Terraces do not act as good control measures. The main predisposing feature of rilling is the presence of unconsolidated sandy residual soils, with high erodibility index and an opportunity for concentration of water into the channels caused by animal activities. The rills have a great impact on water quality due to high sediment load and they require much rehabilitation to remedy.

## Ravine

Ravines are found on linear/concave slope with a declivity around 25º at a frequency of about 2 ravines/ha. Each one is about 1m wide, 1m deep and from 10 to 50m long (Figure 4 to 6). They develop due to the combined occurrence of unconsolidated sandy soils and water concentration resulting from deforestation, a steep slope and high rainfall. These features have a high progression potential with a severity varying from low to moderate, temporary water flow and there are, at present, no control measures.

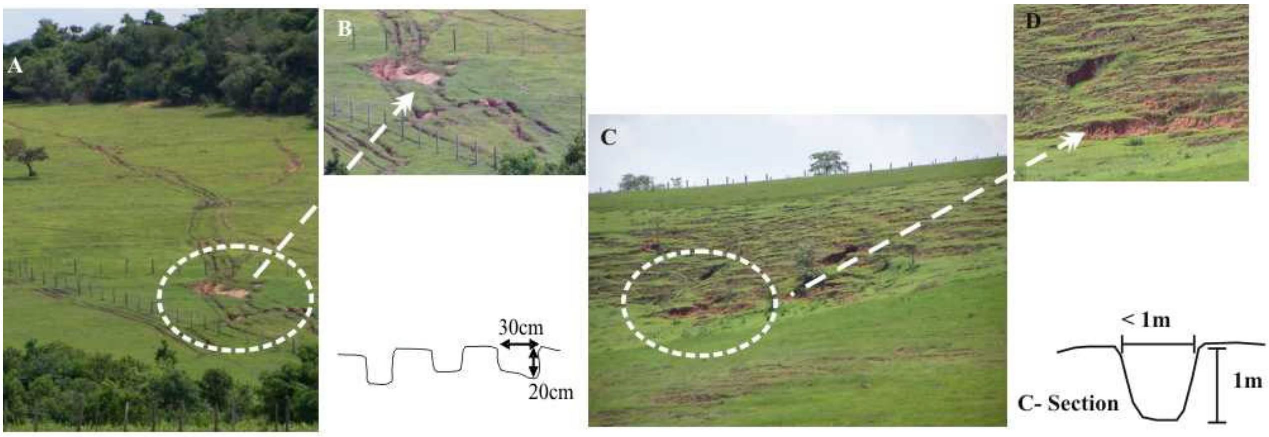


**Figure 6.** (A) General view of the rills, (B) Detail and cross-section of rill, (C) Ravine and (D) detail and cross-section of ravine.

## Gully

These features occur in convex/linear/concave collector slope, with declivity around 25º. They are 150m wide, 50m deep, and 120m long and lie orthogonally to the Aécio channel (Figure 7). There are 3 main branches having low angularity and variably sloping sides . The area affected is about 12,500m$^2$ and eroded volume is about 70,000m$^3$. Gullies develop due to a combination of factors, such as the presence of transported soil orunconsolidated saprolitic residual soils, both with high erodibility indices, very steep slope, and intense rainfall.

The gully shows different activity conditions (active, dormant, stable), high severity degree, and 3 main branches. The drainage system in the area is affected by the gully progression and the water and soil qualities are both damaged.

## Streambank erosion

Streambank erosion is found in all rivers of the area and in terrace landforms and slopes, with or without riparian vegetation. Figure 8 shows an example of a 2m high, 50m long streambank where around 150m$^3$ of material has been eroded. The eroded bank is composed of weathered rock underlying sandy alluvial material. These streambank features are due to river bend and flooding conditions. The feature is covered by vegetation; but the toe and upper bank are eroded. There no are control measures and they continue to grow. The process affects bridges, the quality of the water and rate of siltation.

## Road erosion

Both paved and unpaved roads are affected by erosion processes in that natural and man-made slopes are eroded due to discharge from surface water drainage systems and the roadway. Figure 9 shows examples recorded in the Barra watershed.

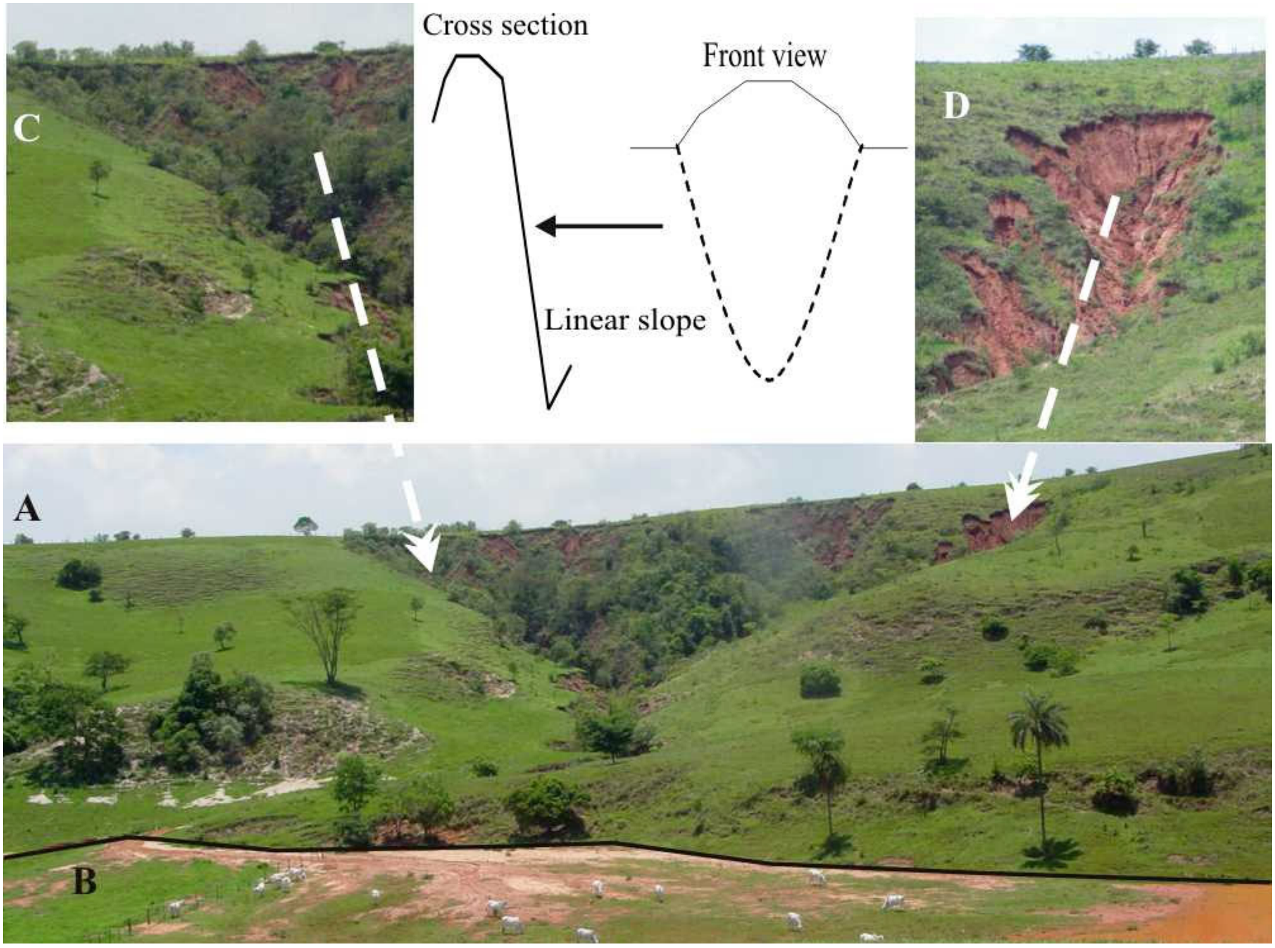


**Figure 7.** (A) General view of gully (see different activity conditions), (B) Sedimentation zone, (C) Vegetated portion and (D) Reactivated zone.

**Figure 8.** Streambank erosion process.

# CONCLUSION

Water, soil and pasture quality, and environmental aspects are strongly affected by erosion processes. The datasheet method permitted good control and efficiency in fieldworks during the inventory, leading to homogeneity of data for all features recorded in the region. The data recorded in the datasheets can be used for several purposes, including control, rehabilitation and monitoring measures, and the evaluation of the loss during specific period, as well as databank developments in the future.


**Figure 9** - Slope and road affected by erosion process (a- ravine, b- control measure, c- slipping and d- gully).

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