Fachhochschule Köln
Cologne University of Applied Sciences

UNIVERSIDAD AUTÓNOMA DE SAN LUIS POTOSÍ

**FACULTADES DE CIENCIAS QUÍMICAS,
INGENIERÍA Y MEDICINA**

PROGRAMA MULTIDISCIPLINARIO DE POSGRADO
EN CIENCIAS AMBIENTALES

AND

**COLOGNE UNIVERSITY OF APPLIED SCIENCES
FACHHOCHSCHULE KÖLN**

INSTITUTE FOR TECHNOLOGY AND RESOURCES
MANAGEMENT IN THE TROPICS AND SUBTROPICS

"SOIL EROSION ASSESSMENT IN THE AGRICULTURAL MICROBASIN OF PITO ACESO IN THE MUNICIPALITY OF BOM JARDIM, RIO DE JANEIRO STATE"

THESIS TO OBTAIN THE DEGREE OF

**MAESTRÍA EN CIENCIAS AMBIENTALES
GRADO OTORGADO POR LA UNIVERSIDAD AUTÓNOMA DE SAN LUIS POTOSÍ
Y
MASTER OF SCIENCE
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SAN LUIS POTOSÍ, MÉXICO **JULIO DE 2010**

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SAN LUIS POTOSÍ, MÉXICO **JULIO DE 2010**

PROYECTO FINANCIADO POR:

CLIMATE CHANGE, LANDSCAPE DYNAMICS, LAND USE AND NATURAL RESOURCES IN THE ATLANTIC FOREST OF RIO DE JANEIRO-DINARIO PROJECT, PROYECTO FINANCIADO POR EL MINISTERIO ALEMÁN DE EDUCACIÓN E INVESTIGACIÓN (BMBF) Y LA EMPRESA BRASILERA DE INVESTIGACIÓN AGROPECUARIA (EMBRAPA)

PROYECTO REALIZADO EN:

EMBRAPA SOLOS

INSTITUTO DE INVESTIGACIÓN DE ZONAS DESÉRTICAS (IIZD) DE LA UNIVERSIDAD AUTÓNOMA DE SAN LUIS POTOSÍ

CON EL APOYO DE:

DEUTSCHER AKADEMISCHER AUSTAUSCH DIENST (DAAD)

CONSEJO NACIONAL DE CIENCIA Y TECNOLOGÍA (CONACYT)

LA MAESTRÍA EN CIENCIAS AMBIENTALES RECIBE APOYO A TRAVÉS DEL PROGRAMA NACIONAL DE POSGRADOS (PNP - CONACYT)

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ACKNOWLEDGEMENT

1. To God for giving all what I have.

2. To my mother Ana Leny Villarreal for her unconditional support and wise words and for been that example mother who would give everything and do any sacrifice in order to see her sons and daughters become professionals.

3. To my sister Katherine and my brothers Mario José and Mario Alexander for always been there when I needed someone to talk to and share my feelings with.

4. To Mr. Dario Chirú who has played a very important role in my life in the last years, by offering me his unconditional support and treating me as his sons.

5. To Dr. Udo Nehem that besides a thesis director was also a good friend that provided me with valuable advices along this journey.

6. To Dr. Jose Luis Flores Flores that despite all the difficulties and distance was always in the better disposition to play his role as thesis director guide me, clarifying my doubts and question and providing with good advices.

7. Special thanks to Dr. Ana Paula Tureta and Dr. Guilherme Donagema, that played a very important role in the development of this research. They acted as co-advisers and provided me with all the technical assistance and research guidance I needed.

8. To all the ENREMs, my classmates, that always supported and encouraged me to finish this journey.

ABSTRACT

In rural areas inappropriate land use generates soil problems such as soil particles dissociation, reduction of soil fertility and agriculture productivity. For the Serrano Region of Brazil the mixture of natural and anthropogenic processes such as high precipitation regimens, very steeped relief, deforestation, and agriculture in slopes are predominant factors that enhance these soil problems. The objective of this research is to assess the landscape vulnerability to water erosion of the agricultural micro-basin of Pito Aceso in the Municipality of Bon Jardim in the State of Rio de Janeiro. The research is divided in two parts: a) A desk research: which consists of a literature review, generation and interpretation digital maps and; b) A field assessment: which consists of the identification of different types of: a) Soil erosion; b) Support practices and; c) Crop and cover management tendencies. Results indicates that Pito Aceso presents a rough relief with moderate to severe erosion in areas dominated by clean pastures (CP), moderate erosion in areas under annual (AC) and perennial cropping (PC) and light erosion in areas under forest. Also it is found that in Pito Aceso the more vulnerable areas to erosion are areas in Cambisols and Latosols under CP and AC in slope with very strong, strong and medium gradient, followed by areas under PC with very strong and strong gradient. In general Pito Aceso presents a rough relief which demands a careful land use planning and the adoption of soil conservation practices.

Keywords: soil erosion, slope gradient, trampling effect, rill erosion.

RESUMEN

En áreas rurales el uso inapropiado del suelo acarrea problemas como la disgregación de partículas, reducción de fertilidad y productividad. Para la Región Serrana de Brasil la combinación de procesos natural y antropogénicos como la alta precipitación, relieve accidentado, deforestación, agricultura en laderas favorecen estos problemas en el suelo. El objetivo de este trabajo es evaluar la vulnerabilidad del paisaje a erosión por escorrentías en la micro-cuenca agrícola de Pito Aceso en la Municipalidad de Bom Jardim en el Estado de Río de Janeiro. La investigación está dividida en dos partes: a) Investigación de escritorio, el cual se basa en una revisión bibliográfica y la generación e interpretación de mapas digitales y b) Trabajo de campo, que consiste en la identificación de tipos de: a) Erosión; b) Practicas de conservación y; c) Tendencias de ordenación de cultivos (cubierta vegetal). Los resultados indican que Pito Aceso presenta un relieve accidentado con erosión moderada a severa en áreas cubiertas por pastos limpios, erosión moderada en áreas con cultivos anuales y perennes y erosión mínima en áreas cubiertas por bosques. También indican que en Pito Aceso las áreas más vulnerables a erosión son las áreas en Cambisolos y Latosolos en: a) Pasturas y Cultivos Anuales en pendientes con declividades muy fuertes, fuertes y medias y b) Cultivos perennes en pendientes con declividades muy fuertes y fuertes. En general Pito Aceso presenta un relieve accidentado que requiere de un planeamiento de uso del suelo cuidadoso y la adopción de medidas conservación de suelo.

Palabras claves: erosión de suelo, pendiente, efecto de pisoteo, erosión en surcos.

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1. BACKGROUND

1.1. The Atlantic Rain Forest

During the conquering period of Brazil by the Portuguese in 1500 (Lino, 2003), the Atlantic Rainforest was one of the largest rainforests of the Americas, initially covering around 150 million ha in highly heterogeneous environmental conditions. It originally extended from 3 ^oS to 31 ^oS, and from 35 ^oW to 60 ^oW mainly along the Brazilian coast (92 %) (Gianerirni et al, 2008) crossing 17 Brazilian states and reaching into Paraguay and Argentina (Rodrigues et al., 2007).

The wide longitudinal range of the Atlantic Rainforest is also important in producing differences in forest composition, because of the decreased rainfall away from the coasts (Ribeiro et al., 2009). Coastal areas receive large amounts of rain year-round, reaching more than 4000 mm, while inland forests receive around 1000 mm/year. These geographical characteristics, combined with the large altitudinal range to up to 2700 meters a. s. l. (Rodrigues et al, 2007) have favored high diversity and endemism. The biodiversity in the Atlantic Rain Forest more than 20,000 species of plants, 261 species of mammals, 620 species of birds, 200 species of reptiles and 280 species of amphibians, from which 30%, 61%, 12%, 30%, and 90% respectively are endemic (Rodrigues et al., 2007), and many more species that still require scientific description (Ribeiro et al., 2009).

Associated to the Atlantic Rainforest exist three main vegetation classes, that group several physiognomically and floristically distinct forests: mangroves, ‘‘restinga” (lowland forests on sandy soils near the coast) and forests (including coastal forests, Araucaria mixed forests, and semi-deciduous forests) (Ribeiro et al., 2009). The punctual richness of this biome is so representative that the two mayor world records of botanical diversity for woody plants were registered here: 454 species in one hectare to the south of Bahia and 476 species in an area of the same size in the Serrano Region of Espírito Santo (Galindo-Leal et al., 2005). Therefore the Atlantic Rainforest presents the biggest biodiversity in tree species per hectare of the planet (Correa, 1996).

According to Ribeiro (2009) the Atlantic Rainforest's flora and fauna may include 1–8% of the world's total species. For this reason the Atlantic Rainforest is today considered one the tropical forest more threaten in terms of extinction and one of the "hotspots" of world biodiversity and area of priority for its conservation at a global level (Lino, 2003).

Since XVI century to the XX century the economic cycles related to commodities such as "pau brazil" (Caesalpinia echinata) or brazialian tree, sugar cane, cattle rising, and coffee had big impact in the Brazilian economy, but also the development of all theses commodities caused serious damages to the Atlantic Rainforest due to the implementation of not sustainable practices that would have turned possible to overcome the economic and social contradictions of the Colony (Galindo-Leal et al., 2005).

In the Atlantic Rainforest the first economic cycle began with the exploration of "pau brazil" by the colony, the first product of commercial interest then abundant in the forest of Rio de Janeiro to Ceará (Galindo-Leal et al., 2005; Rodrigues et al, 2007). According to SOS Mata Atlantica (2005) trees of this specie were extracted with such intensity (around 2 millions trees in a 100 years) that in 1558 the viable reserves were more than 20 kilometers inland. The timber was continuously used for all the purposes due to the lack of fuel sources. Another important activity during the first centuries of colonization was the extensive cattle rising, big amount of livestock opened space for posterior human settlements and wide areas were burned and cleared for the creation of grasslands, altering seriously the environment (Rodrigues et al, 2007).

In the XVIII century, sugar cane was widely distributed throughout the colony, it was found all along the coastal fringe from the extreme of north of Pará, to the south in the Santa Catarina, situation which ended with vast extensions of forest (Ferreira, 2008; Rodrigues et al, 2007). As introduced exotic specie, sugar cane did not affect a specific natural resource, but rather placed pressure on the Atlantic Rainforest as an entire entity. The sugar cane production carried with it severe forest clearing of fertile areas of the northeast littoral for the production and culture of wood to be used as fuel in the sugar refinery (Galindo-Leal et al., 2005).

In the XIX and XX centuries began the coffee production, and big areas were planted in several Brazilian states. By then coffee was the principal source of income in Brazil that also brought with it inappropriate land use practices that accelerate the loss of forested area in the southeastern region of the country (Galindo-Leal et al., 2005).

The destruction of the Atlantic Rainforest speeded exponentially in XX century due to intensive process of urbanization, agriculture expansion, massive industrialization and economical development (Rodrigues et al., 2007; Lino, 2003; Taberelli et al., 2005).

Nowadays in its Brazilian fraction the Atlantic Rainforest covers not more than 8% of its original extension and it is the dramatic result of an occupation with devastating effects. There were 500 years of a soil use and occupation policy that converted this biome in one the most threaten of the world (Correa, 1996).

Since the first stages of colonization of Brazil the Atlantic Rainforest has gone through a series of outbreaks of forest conversion, with the final results of a landscape strongly dominated by humans (SOS, 2005) where agriculture the most relevant (Lima et al., 2008).

The accelerated fragmentation process of the Atlantic Rainforest turned it into one area of priority in terms of biological conservation, since big number of the fragments suffer certain degree of anthropogenic perturbation (Dario et al, 2002). Most of the remaining fragments of the Atlantic Rainforest exists in small fragments (<100 ha) that are isolated from each other and are composed by second-growth forests in early to medium stages of succession. (Ribeiro et al., 2009). The protection of these fragments is a major guarantee for the geological stability of the Atlantic Rainforest, therefore avoiding the big catastrophes that happened where forest clearing took place, with social and economic extremely serious impacts. (Galindo-Leal et al., 2005).

According to Lino (2009) the Atlantic Rainforest survived principally in the states of Espírito Santo, Rio de Janeiro, São Paulo, Paraná and Santa Catarina, forming a big biological corridor due to the rough relief and relative poor soils that characterized the south and southeast of Brazil. This situation which in one hand favors the conservation of this region in the other makes it more vulnerable to perturbations in terms of soil degradation via erosion and nutrients lixiviation (Gianerini et al, 2008)

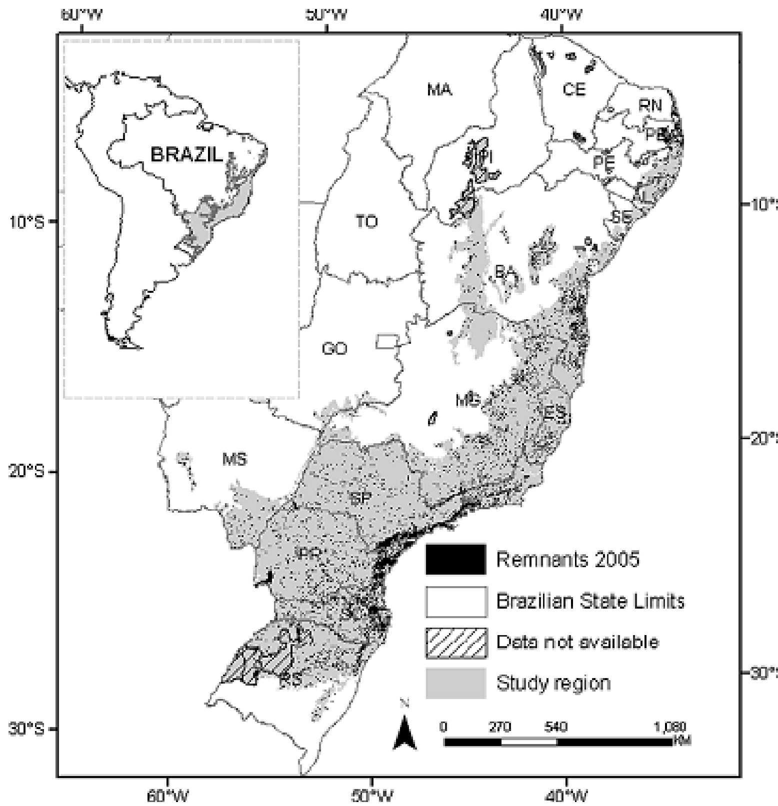


Figure 1. Remaining forest of the Rain Atlantic Forest. Sources: Ribeiro et al, 2009.

1.2. INTRODUCTION

In rural and urban areas inappropriate land use generates soil problems such as: soil loss by the detachment of particles (that decrease soil fertility and agriculture productivity), silting of water bodies and contamination of water courses with agro-toxics and chemical products that are washed together with the soil particles (Machado et al., 2007). Therefore it is necessary the characterization of soils, topography, geomorphology, hydrology and anthropogenic erosion in order to establish the right land use for a given area (Endres, 2006). In terms of agriculture land use Paes et al., (2004) cited that the appropriate use of agricultural land is of relevant important because it minimizes the existing problems and keeps the potential of soils still untouched. In the tropics these types of assessments are of high relevance since this region presents special hydrological and geomorphologic features such as rough and steep relief and intense and long precipitation patterns, situation which could enhance degradation processes such as soil erosion (Da Silva, et al 2006). Soil erosion assessment, which is part of the diagnosis of environmental problems, is highly relevant since inadequate land use can accelerate soil losses and depositions that occur naturally. Thus leading to modifications related to soil conservation, water production and quality, and environmental changes in certain locations of a drainage basin (Blanco, 2009).

The Brazilian territory is characterized by a big diversity of soil types, corresponding directly to the intensity of manifestation of different forms and types of relief, climate, soil parent material, vegetation and associated organism, which creates the different conditions for soil losses and formations (Blanco, 2009). In the Serrano Region-South Easter Brazil Forest the mixture of natural and anthropogenic processes such as: high precipitation regimens, very steeped relief, deforestation, and agriculture in slopes are predominant factors that enhance the probabilities of soil degradation specially soil erosion. Endres et al., (2006) stated that among the negative effects of deforestation, the most known is erosion. Added to this situation there exist the presence environmental unfriendly practices such as short fallow period, limiting the recovery of original soil properties, reducing in consequence soil infiltration rate, and increasing runoff and erosion (Miranda et al., 2009).

1.2.1. Research objectives

1.2.1.1. General Objective

The general objective of this research is to assess the landscape vulnerability to erosion of the agricultural micro-basin of Pito Aceso in the Municipality of Bon Jardim, Rio de Janeiro State.

1.2.1.2. Specific Objectives

In order to achieve the general objective of this research there are four consequent objectives:

1.2.1.2.1. To do an integrated analysis among relief aspects, land use systems and predominant soils classes in the region;

1.2.1.2.2. To describe the on-going soil erosion processes and assign their possible causes.

1.2.1.2.3. To analyze the effects of current land use systems on soil stability;

1.2.1.2.4.To generate a landscape vulnerability map of the study region.

2. STATE OF THE ART

2.1. Soil

Teixeira et al., (1996) defined soil as the result of the integrated action of climate and organisms on parent material conditioned by relief in different period of time. Result that presents characteristics that constitute an expression of the dominant processes and of the mechanisms in its formation. Teixeira et al., (1996) mentioned five predominant factors in soil formation:

a) Climate: the weathering of rocks is directly influenced by meteorological factors like temperature, precipitation and humidity, thus producing the material that originates soils; b) Organisms: their action in the decomposition and/or transformation of organic residues supplies soils with mineral salts and elaborate Humic substances that help to built physical and chemical properties; c) Parent material: the nature of the texture, mineralogy and chemistry of the parent material influences the soil characteristics; d) Relief: it affects the development of soils by the influence on water dynamics, erosion, microclimates; e) Time: the age of soil is validated in function of the degree of the development of soil horizons and presence or not of primary mineral with low resistant to weathering. (soil properties)

According to Neto and Lombardi (1999) the principal soil physical characteristics are: a) texture; b) structure and; c) porosity.

2.1.1. Soil texture

Neto and Lombardi (1999) refered to soil texture as the quantitative distribution of the different classes of particles that form soils; Brady et al., (2004) refered to these particles as the fragments that are part of the fine earth fraction, which is formed by clay, silt and sand particles. Related to earth fine fraction the International Society of Soil Science classifies it as follow: a) clay: particles smaller than 0.002 mm; b) silt: particles between 0.002 mm and 0.02

mm and; c) sand: this class is divided into fine and core, both are bigger than 0.02 mm, but smaller than 0.2 in the first case and 2 mm in the second case. Therefore soils can have core or fine texture, either when sand or clay particles predominates, in which case soils are called light or heavy respectively (Freire, 2006).

2.1.2. Soil structure

Freire (2006) defined structure as the arrangement of the different types of particles that form soils (clay, silt and sand) in secondary particles or aggregates. FAO (2005) referred to soil structure as the natural organization of soil particles into discrete soil units result from pedogenic process. Thus soil structure is classified according the size, shape and degree of development Neto and Lonbardi (1999) In terms of shape soils can have spheroidal, platy, primslike or blocklike shape while in terms of size they can be fine, medium or coarse structured and in terms of development they can be strongly,

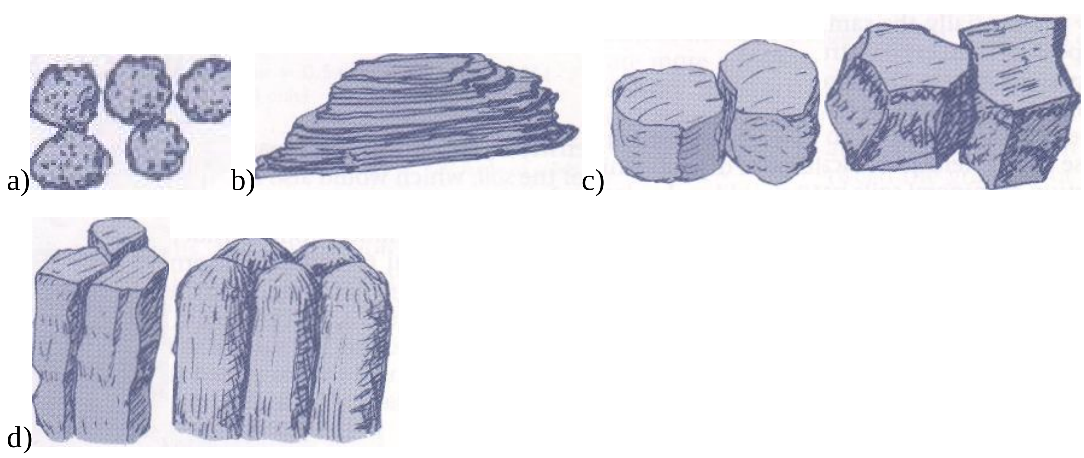


Figure 2. Different structures types found in soils: a) Spheroidal, b) Platelike, c) Blocklike d) Primslike. Taken and modified from Brady et al, 2004

moderately or weakly developed (Brady et al., 2004). Soil structure is important due to its close relation with soil aeration, water filtration and plants' root development processes, subjects close related to soil porosity. (Neto and Lombardi, 1999).

2.1.3. Soil porosity

It refers to portion of soil occupied by air and water and it depends of the arrangement of the soil solids particles (Freire, 2006). Related to pores size they can be classified in macro-pores (bigger than 0.08 mm) and micro-pores (smaller than 0.08) that are related to well structured or fine soild or granular structured soils respectively (Brady et al, 2004). According to Neto e Lombardi (1999) the loss of porosity in the soil is associated to reduction of organic matter, soil sealing and the effects of the impact of rain drops that reduces the size of aggregates and therefore the size of the pores.

2.2. Erosion

Soil degradation can be considered as one of the most important environmental problems nowadays, that result from the inadequate agriculture management (Panachuki et al., 2006), highlighting water erosion as one process of soil degradation that affects at most the productivity capacity of soils. Vitte et al., (2006) defined erosion as the process of detachment and washout of soil particles caused by water and wind. This process is sequenced by Panachuki et al., (2006) as follow: a) Detachment of soil particles from soil aggregates that can remain close to the aggregate or be transported; b) Washout or transport which is done by the surface runoff and; 3) Deposition of particles in body water.

Erosion is a process that occurs naturally in the environment slowly and gradually; it is responsible for the sculpturing of terrestrial crust and landscape development, being conditioned by factors such as climatic regimes, relief, soil type, geomorphology, phyto-geography (forest, grassland, etc) (Endres, 2006; Vitte et al., 2006). According to Vitte et al, (2006) this process is considered normal or natural when there is an equilibrium between the process of soil formation and soil loss.

However with human intervention this trend might be altered through the occupation and intensive use of soils with practices such as: deforestations, introduction of seasonal crops leaving the soil unprotected, by intensification of agriculture, overgrazing, and improper maintenance of plantations, leading to higher soil losses. This type of accelerated erosion is known as anthropogenic erosion (Pla, 1997; Vitte et al., 2006).

Water erosion processes have been accelerated in most of the tropical regions in recent decades, due to population pressure and limited resources, which have also led to increased the use of steeper lands for agriculture (Pla, 1997). According to Dias et al., (2001) the human land occupation represents a determinant factor in relation to the acceleration of erosive processes, which are commanded for the following natural factors:

a) Volume of water that exerts the soil: Volume of water and its distribution in time and space determines the velocity of erosive process;

b) Vegetation cover: The type of cover determines how much protection soils have against the impact of rain and removal of soil particles by water.

c) Type of soil and parent material: Determine the degree of susceptibility of soil to erosion (erodibility), in function of its texture (clay, silt, sand), structure and soil depth.

Lobo et al., (2003) divided the factors that affect erosion processes in three categories:

a) Energy factors: including rainfall erosivity, runoff volume, wind strength, relief, slope angle, slope length; b) Protection factors: including population density, plant cover, amenity value (pressure for use) and land management and: c) Resistance factors: which includes soil erodibility, infiltration capacity and soil management.

Among the most serious consequences of soil erosion it is possible to mention: a) Changes in farm productivity, b) Damages from uncontrolled runoff: c) Siltation of water bodies and d) Environmental alteration in flow of sediments in oceans lakes (El-Swaify et al., 1982).

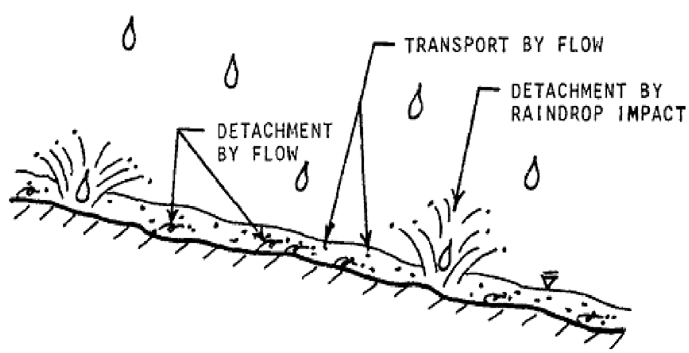
Is like this that in 1978 Wischmeier and Smith set up the basis for evaluating and measuring water soil erosion trough the development of the Universal Soil Loss Equation, defined as follow:

$$A = RxKxLxSxCxP$$

Where: A = soil loss per unit area; R = rainfall and runoff factor; K = soil erodibility factor; L = slope length factor; S = slope steepness factors; C = cover and management factor and; P = support practice

2.2.1. Rainfall and Runoff or Factor (R)

Figure 3. Sediment detachment and transport. Taken from beasly et al., 1981



The humid tropics are characterized by large quantities of annual rainfall and frequent and intensive rainstorms (El-Swaify et al., 1982). Therefore the susceptibility of soils in the tropics to surface water erosion is higher than in other climatic regions of the World (Vitte et al.,

2006; Pla, 1997). As an active force, precipitation exerts its erosive action trough the impact of rain drops that reach ground with variable velocity and energy. This erosive action of precipitation depends on: the rain drops diameter and outflow of runoff that has a velocity and volume varying according to the slope inclination and length, soil drainage capacity and passive forces (Vitte et al, 2006). The rain erosive force is attributed to its kinetic energy or momentum, parameter related to intensity and quantity. Therefore the erosive force of rain is divided into two parts: the direct impact of the drops and the runoff that precipitation generates.

Relate to the impact of rain drops Wischmeier et al., (1975) stated that medium size raindrops increases with rain intensity and terminal velocity of free falling water drops increase with the increased drops size, therefore increasing the capacity of water drops to detach soil particles.

2.2.2. Support Practice or Factor (P)

Support practice or factor P makes reference to the relation between the expected amount of soil loss that would occur with the use of a given conservationist practice and the loss that would with up and down slope agriculture (Vitte et al, 2006). Wischmeier and Smith (1978) highlighted that agriculture in slope needs to be backed up with practices that reduce surface runoff such as: contour tillage, strip-cropping and terrace systems.

Land Use	**CP Values**
Forest	0.00004
Silviculture	0.0001
Citrus	0.02
Coffee	0.02
Sugar cane	0.02
Pasture	0.01
Annual culture	0.02

Table 1. Land Use and CP values. Taken from Vitte et al., 2006.

Soil tillage plays a major role in changing physical and hydrological properties of soils through the time, and in consequence dynamics of soil water infiltration and soil erosion.

2.2.3. Slope length (L) and gradient (S)

Both length and the gradient of the slope substantially affect the soil erosion by water (Wischmeier et al, 1978). Wischmeier et al., (1965) established the LS factor as the expected ratio of soil loss per unit on a field slope to a corresponding loss from the basic 9% slope, and 72.6 feet long. Slope length is defined as the distance from the point of origin of overland flow to either the point where the slope decreases to the extent where deposition begins or the point where runoff enters a well-defined channel part of drainage arrangement. In terms of slope gradient Wischmeier and Smith (1975) stated that runoff in usually increases with the increased slope gradient (percentage), but this is influenced by factors such as type of crop, surface roughness, and soil infiltration capacity. Adding to this Dias et al., (2001) stated that steeper and longer slopes increase the velocity and time of runoff thus increasing erosive capacity and amount of eroded soil respectively.

2.2.4. Soil erodibility or Factor (K)

The susceptibility to erosion of soil is defined as erodibility, it is represented as factor K and is related to the relationship between soil loss and rain erosivity (Wischmeier and Smith, 1965; Mannigel et al., 2002). In other words is the integrated effect of processes that regulate water infiltration and the soil resistance to the degradation of particles for later transport (Machado et al., 2007; Vitte et al, 2006). These processes are influenced by soil properties such as particle size distribution, structure stability, organic matter content, origin of clay mineral, chemical constituents, porosity aggregates stability and pH. This due to soil characteristic' dynamism, their susceptibility to alteration by different land uses, land tenure, agriculture systems, thus erodibility features also change along the time (Vitte et al, 2007; Machado et al., 2007; Teixeira et al., 1996). Very close related to soil erodibility is the soil loss tolerance, which is understood as the acceptable quantity of soil than can be lost due to anthropogenic erosion that keeps the initial soil fertility levels and its equivalent productivity; it is measured as tons per hectares per year (t/ha.year) Mannigel et al, (2002).

Include table of rain erosivity.

2.2.5. Cover and Management system of Factor (C).

Cropping and management factors or factor C according to Wischmeier and Smith (1978) is defined as the proportion of soil loss from a giving crop under a given management from a continuously tilled followed area Laflen et al., (2003). Teixeira et al., (1996) stated that vegetation cover reduces erosion rates trough the possibilities of reducing the kinetic energy of rain trough the interception by the canopy and humus formation, important for the stability of soil aggregates. Soil vegetation cover also has importance in the drainage and reduction of surface runoff; it reduces the velocity of superficial runoff by the formation of mechanic barriers trough the reduction of sediments transport, thus reducing soil loss up to 90% and the velocity up to 62% (Endres et al., 2006). According Endres et al., (2006) forest constitutes together with other types of vegetation such as natural grassland the best cover to resistance against erosion.

Thus, the removal of vegetation cover for a further conversion to agriculture land promotes the alteration of some elements from the local physical environment; principally those related to soil (Machado et al., 2007), while cropping in different stages of development offers different degrees of protection, which lead to differences in soil loss together with incidence of climatic factors, the resistance of the soil and the management of crop residues (Paes et al., 2004). This protection depends on the type of vegetation, quality of growth and the different months or seasons. Therefore the effectiveness in protection would depend in general of combination of good soil cover during the period with the most erosive rain (Wischmeier et al., 1978). Related to soil cover protection Vitte (2006) cited Bertoni e Lombardi Neto (1990) that classified this protection as follow:

- D period (soil preparation): from soil preparation to sawing;
- Period I (sawing): from sawing to the first month after sawing;
- Period II (establishment): from first month to the second month;
- Period III (grow and maturity): from the second month to harvest and;
- Period IV (from harvest to soil preparation).

3. STUDY AREA

3.1. Localization

The Pito Aceso micro basin is an area of about 500 hectares located in the 4th district, Barra Alegre, of the Municipality of the Bom Jardim, in the Serrano Region of Rio de Janerio, Figure 4.

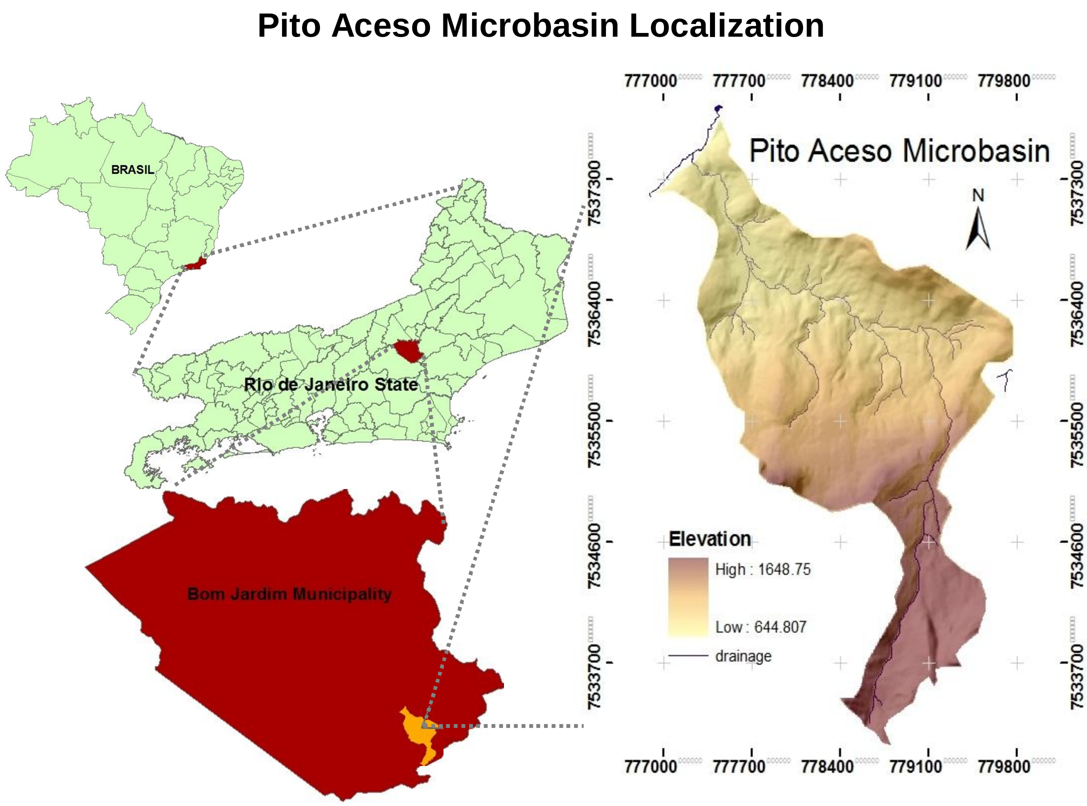


Figure 4. Study area localization

3.2. Geomorphology

The study area is located in the geomorphologic unit of slopes and costal range of Serra dos Orgaos plateau. It is part of the Mountain Chain Serra do Mar, orientated SO-NE (Mendez et al, 2006; CIDE, 1997)

Figure 5. Pito Aceso Microbasin overview

This sector of the Serrano Region is mountainous in relief, with steepness ranging from 45 to 60% and altitudes around the 900 meters a.s.l. (Mendez et al, 2006). It presents a metamorphic lithology with rocks predominantly of granitic and gneissic origin (Mendez et al, 2006) and tts origin dates from the Pre-Cambrian period, these are rocks rich in minerals like quartz, feldspar and mica (Teixeira et al, 1996).

All these hills were once covered by humid tropical forest that nowadays are greatly altered or cleared by human activity (Teixeira et al, 1996).

3.3. Climate

The climate predominantly is moderate mesothermic humid (subtropical humid climatic group - Cfa). The annual average temperature ranges from 18 to 19ºC, with an annual precipitation of 1, 400 mm falling during the summer or rainy season (October to March) (Da Costa et al, 2007; Lima et al, 2008; Prado et al, 2009).

According to Nimer (1989) precipitation regimes in this region are the result of the interaction of latitudinal and orographic factors. In one hand, the latitudinal location close to the Equator and the incidence of solar rays enhances evaporation processes inland and in the vast Atlantic littoral to the east and in the other hand the orographic formation of the region enhance precipitation by increasing turbulence with the uplifting of Polar and Atlantic air currents.

3.4. Soils

Soils of the Atlantic Forest are generally poor in primary minerals, these soils are granitic and gneissic in origin and most of the nutrients are found in the live biomass above it (Gianerini et al, 2008). The soil classes commonly founded in this region are mineral non-hydromorphic, including: a) Cambisols; b) Argisols; c) Latosols; d) Neosols, with their respective sub categories (Da Costa et al., 2007; Lima et al., 2008; Prado et al., 2009; Campos de Abreu et al, 2008; Mendez et al, 2006; EMBRAPA Florestas, 2009).

3.4.1. Cambisols

The concept of this soil class makes reference to low development with incipient B horizon, and medium to high in clay contents. The material below the A horizon in this soil has not advanced edaphical development changes in color and/or structure. It has an incipient B horizon, half of it coming or not from underlying parent material (Teixeira et al., 1996). The sequence of horizons in this soil is A, Bi (B incipient), C or A, Bi, R (rock) and can have variable depths. The minor differences in the clay content between the superficial and sub-superficial horizons, the Cambisols are less prone to erosion than for example Argisols (EMBRAPA Florestas, 2009).

3.4.2. Latosols

Latosols are soils with horizons in the sequence A, Bw and C. Latosols have medium to high in clay content and is characterized by the presence of a latosolic B horizon, which is constituted principally by highly weathered mineral clay fraction with low activity. Due to light changes in clay content along the different horizons, this class of soil has low susceptibility to erosion. (Teixeira et al., 1996; EMBRAPA Florestas, 2009).

3.4.3. Argisols

Argisols are soils loamy or clayey in texture, founded in hilly landscapes, Are soils highly developed, with sequence of horizons A, E (eluvial horizon), Bt (B clayey texture), C, or simply A, Bt, C. The differences in clay contents usually founded among the superficial horizon (A) and the sub-surface (Bt), determines the significant changes in the pore quantity, but specially its size (increment in porosity). The alteration in the pores in the horizon Bt, implies less permeability in the sub-surface and a consequent higher surface runoff. This characteristic confers to this soil class a high susceptibility to erosion (EMBRAPA Florestas, 2009).

3.4.4. Neosols

Soils with low degree of development, of variable textures, with sequence of horizons A, C, R, or A above R. The particular feature of this class is the presence of soil profile with lithic contact (low or not altered rock) within the first 50 cm depth. This kind of contact restricts the root penetration and gaseous exchange, and also determines important change in water percolation in the vertical moisture fluxes. All these soil characteristics cause high fragility to the environment (EMBRAPA Florestas, 2009).

3.5. Vegetation

Most of the relics of Atlantic Forest in this region are small fragments, isolated from each other and composed by second-growth forests in early to medium succession stages (Ribeiro et al., 2009). This condition is due to the rough relief, which is not so appropriate for agriculture practices (Rodrigues et al., 2007). The main biome prevailing in this region is the Ombrophile Dense Forest (Mendez, 2006). Some of the plant species dominating in this ecosystem are: Tibouchina sellowianna (quaresmeira da serra), Miconia cinnamomifolia (jacatirão-açu), Hieronyma alchorneoides (licurana), Euterpe edulis (palmito), Nectranda rigida and Alchornea triplinervia (tapiá). (References)

3.6. Agriculture

According to the Tribunal de Contas do Estado do Rio de Janeiro the municipality of Bon Jardim evolved as one important agriculture center of the Serrano Region. This region was one of the main coffee producers after its foundation, declared as City in 1929. The economy of this municipality is based in agriculture, with the coffee as the most important crop followed by corn, beans, tomato, sweet potato, cassava and rice (IBGE, 1959). In terms of production system is identified (Da Costa et al., 2007; Lima et al., 2008; Prado et al., 2009; Campos de Abreu et al., 2008; Mendez et al., 2006) the predominance of non mechanized migratory agriculture of perennial and annual crops mixed with fallows of 3 to 7 years.

4. MATERIAL AND METHODS

The research was divided in two parts: a desk research, which consisted on a literature review, generation and interpretation of digital maps and a field assessment that consisted in the identification of different types of: a) Soil erosion, b) support practices and c) crop and cover management.

4.1. Desk research

4.1.1. Maps Generation and Interpretation

4.1.1.1. Land Use Map

For the evaluation of the different land uses in the study region was used a Land Use Map of the year 2005, created out of two images from the satellite Ikonos II , (February 2002 and May 2004) (Prado et. al, 2009), provided by Embrapa Solos. This map classified the land uses in: a) Late Secondary forest, b) Initial secondary forest, c) Bared soil, d) Annual cropping, e) Perennial cropping, f) Clean pasture, g) Abandoned Pasture, h) Constructed area, and i) Rocky outcrops.

Where:

a) Late secondary forest (LSF): makes references to forest in advance stage of succession;

b) Initial secondary forest (LSF): makes reference to forest in early stages of succession;

c) Bared soil (BS): refers to areas that were under tillage when the satellite pictures were taken;

d) Annual cropping (AC): The predominant annual crops are corn, beans, taro, sweet potato, cassava and in smaller scale some horticultural crops.

e) Perennial cropping (PC): In terms of perennial cropping the predominant crops are coffee and banana and recently introduced Eucalyptus.

f) Clean pasture (CP): Are areas destined to ranching and cattle rising.

g) Abandoned pasture (AP): It refers to pastures that were abandoned or areas that were once covered by grass and now are in initial stages of succession.

h) Constructed area (CA): Makes reference to areas occupied by houses and other facilities.

i) Rocky outcrop (RO): due to the relative young age of the orographic formations and very rough relief of the region there are several areas were process such as rock weathering, intemperism and primary succession are still in process, therefore there is high presence of areas with clifts of naked rock.

Table 2. Percentage occupied by each land use and soil covers. Taken from Prado et al., 2009.

Land use and soil cover	Percentage
Late secondary forest	45.16
Initial secondary forest	18.06
Clean pasture	8.83
Annual cropping	8.36
Abandoned pasture	8.26
Perennial cropping	6.29
Rocky outcrop	3.66
Bared soil	0.75
Constructed area	0.55
Others	0.06
Clouds	0.02

In order to the assessment were excluded from the analysis the following categories: clouds, constructed area and others and rocky outcrops. This was done in order to limit the research to strict agricultural uses.

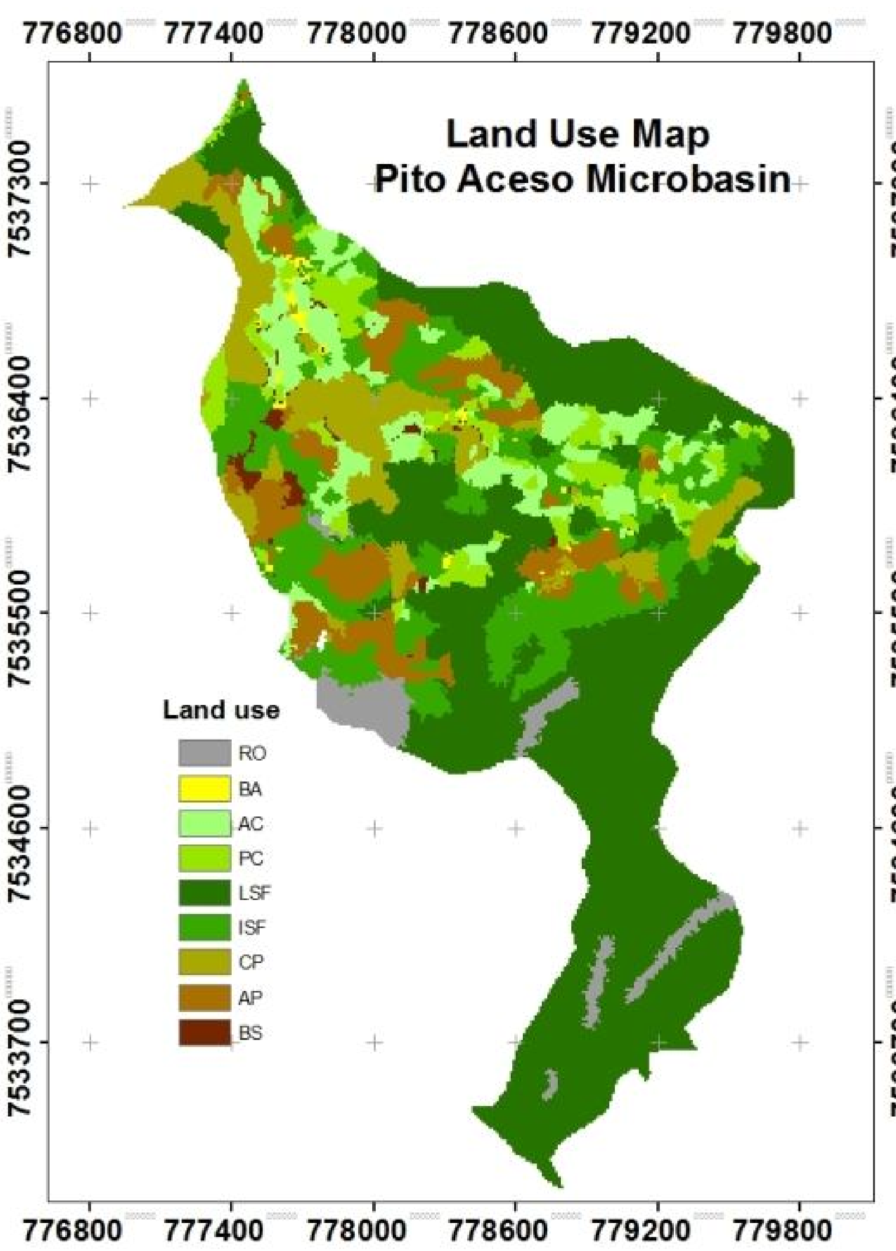


Figure 6. Land use map, Pito Aceso Microbasin. Taken and modified from Prado et al., 2009

Figure 7. Abandoned Pasture

Figure 8. Initial secondary forest and clean pasture.

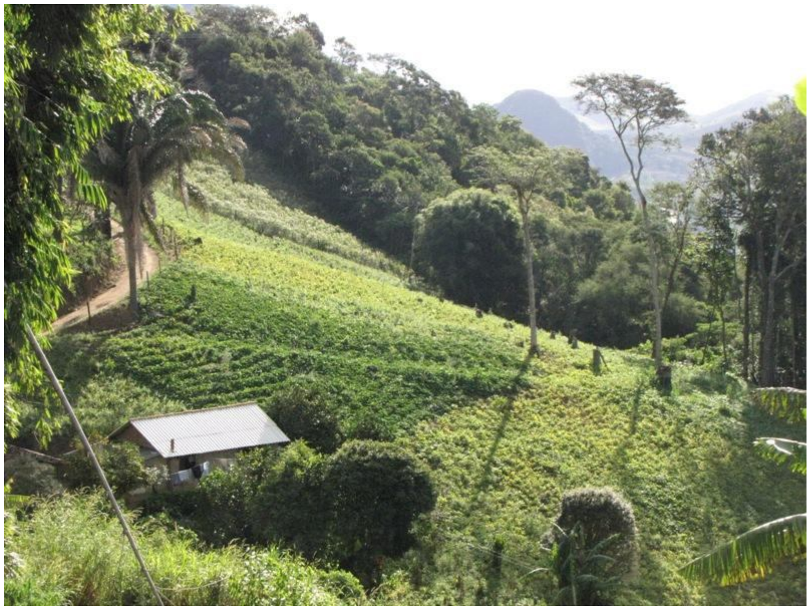


Figure 9. Annual cropping and late secondary forest.

Figure 10. Perennial Cropping-Coffee plantation

Figure 11. Perennial cropping-Banana plantation.

Figure 12. Annual cropping-Cassava plantation

Figure 13. Annual cropping-Bean plantation

Figure 14. Horticulture production plot-Cauliflower.

4.1.1.2. Slope Gradient Map

For this section was first generated a Digital Elevation Model (DEM) from an Countour line topographic layer and a layer containing the boundaries of the micro-basin Pito Aceso, then out the DEM was derived the Slope Gradient Map. This was done using the tools, Topo to Taster for the first case and Slope for the second case, from the 3D Analysis package tool of the software ARCGIS 9.1 (ESRI, Inc., Redlands, CA); the coordinate system used was Universal Transverse Mercator (UTM), datum SAD69, fuso 23. The slope gradient was done based in the classification used for the Serrano region of the Parana by Bigarella et al, 1978; which classified the gradient in 6 categories:

Declivities		
Percentage (%)	Degree (º)	Category
6	1-3	Very weak
6-12	3-7	Weak
12-20	7-12	Medium
20-25	12-24	Strong
>45	>24	Very strong

Table 3. Slope gradient classification, taken from Teixeira et al, 1996.

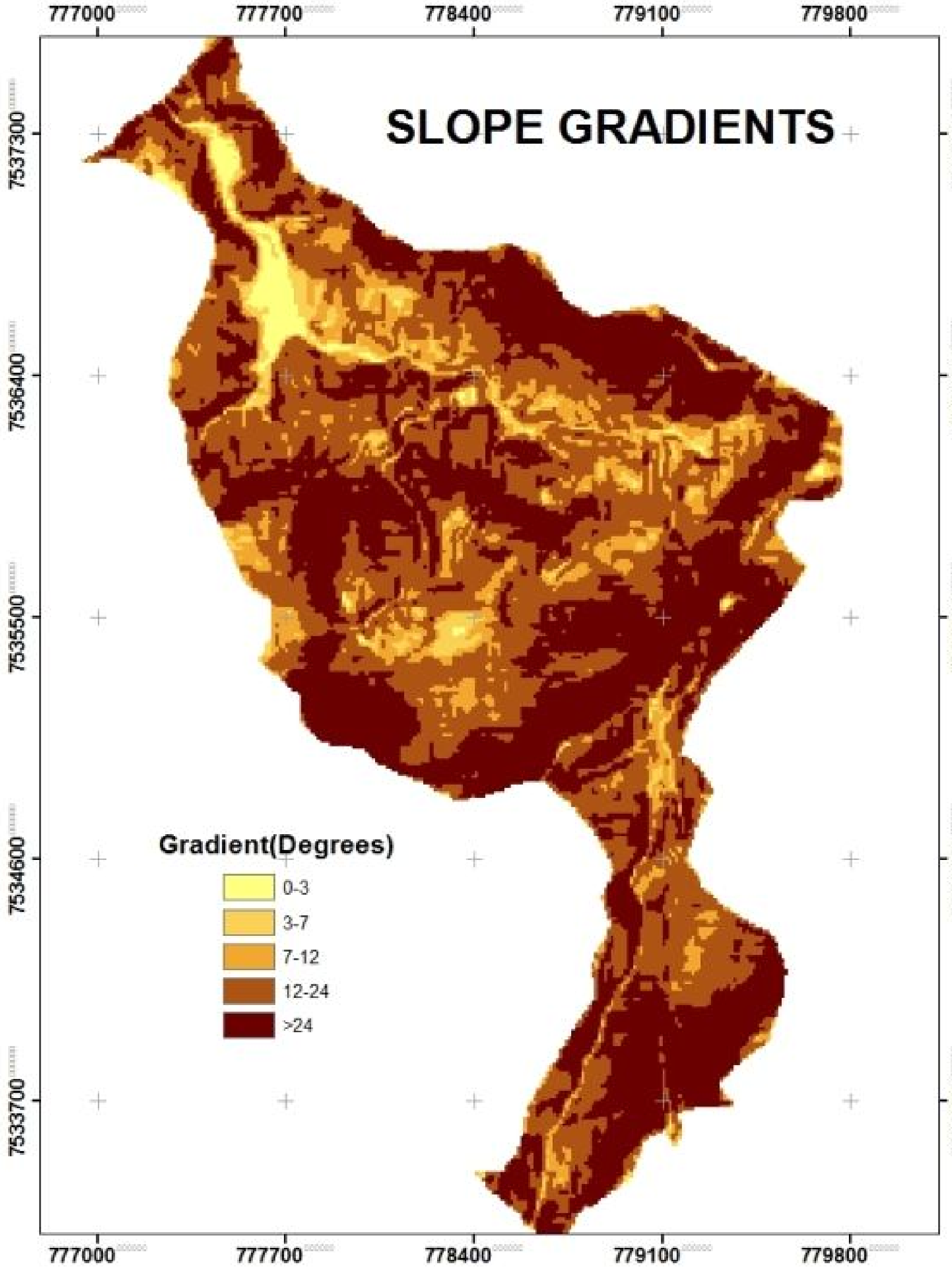


Figure 15. Slope gradient map.

4.1.1.3. Land Use according Slope Gradient

To assess the different land uses according slope gradient was used as reference the uses by gradient proposed by Bigarella et al., (1978) which assigns a land use according to type of gradient as followed

Slope	
Gradient	Recommended use
Very light	Intensive agriculture
Light	Agriculture with moderates conservation measures
Medium	Fallow agriculture with tractor limitation
Strong	Permanent cultures with rotation
Very strong	Mandatory preservation

Table 4. Recommended land use according slope gradient. Taken from Teixeira et al., (1996).

For the generation of the land uses according slope gradient was first done a class reclassification of the land use and slope gradient maps, using classes of 10 to 60 and 1 to 5 respectively, in order to integrate them and do a raster calculation. This was done using the 3D analysis tool “Reclassify” and “Raster calculator” respectively.

4.1.2. Soil erodibility

In the study region were found four main soils classes: Latosols, Cambisols, Argisols and Neosols. To assess the erodibility of the different soil classes were done both a literature review to search for possible already existing data and a calculation of erodibility or Factor K through the equation of Bouyoucos (1965).

$$K = \frac{\frac{\%\, sand + \%\, silt}{\%\, clay}}{100}$$

Where K: is the erodibility factor (t.ha.h/ ha.MJ.mm) and % of sand, silt and clay represent the percentages for each of the fractions. Thus was calculated the erodibility factors for horizon A and B.

Table 5. Soil classes Erodibility.

Soil Group	Erodibility factor t.ha.h/ha.Mj.mm A horizon	Erodibility factor t.ha.h/ha.Mj.mm B horizon	Source
Argissolo Vermelho-Amarelho Distrófico típico	0.0466	0.0100	Mannigel et al., 2002
Argissolo Vermelho Eutrófico tipico	0.0228	0.0112	Mannigel et al., 2002
Argissolo Vermelho Eutrófico abrúptico	0	0	N/F
Cambiossolo Háplico Tb Distrófico latossólico	0.0374	0.0345	Mannigel et al, 2002
Cambissolo Háplico Tb Distrófico típico	0.0254	0.0186	Mannigel et al, 2002
Cambissolo Háplico Tb Distrófico típico	0.0254	0.0186	Mannigel et al, 2002
Cambissolo Húmico Distrófico típico	0	0	N/F
Latossolo Vermelho Distrófico cambissólico	0.021/0.22/0.026	0.21/0.22/0.026	Naves et al., 2000
Latossolo Vermelho Distrófico típico	0.021//0.22/0.026	0.21//0.22/0.026	Naves et al., 2000
Latossolo Amarelho Distrófico húmico	0	0	N/F
Neossolo Litólico Húmico típico	0	0	N/F

4.2 Field assessment

For the field assessment was carried an identification of different types of: a) Soil erosion; b) Soil measures against erosion and; c) Crop and Land cover management. This was done with the help of a Power Shot Canon Digital Camera SX10 IS and a Trimble® GeoXM™ 2008 GPS.

4.2.1. Types of soil erosion

Eroded areas were located then geo-referenced. The identification of eroded areas was done based on erosion indicators such as: exposed rocks or plant roots, presence of rills, inter-rils gullies and land slides (Vigiak et al., 2005).

Indicators definition:

Inter-rill or sheet erosion: Refers to the way that the energy of raindrops affects the whole of the soil surface and consists of the detachment on thin layers of soil by sheet runoff. This is the initial stage of soil degradation from erosion (Rodrigues, 2003; Roose, 1996);

Rill erosion: Channel over 10 centimeters deep that drains following the lines of mayor gradient that can be eliminated through cropping techniques. Rills occur in places where runoff concentrates (Rodrigues, 2003; Roose, 1996);

Gully erosion: Channels with steep lateral walls in general with flat bottom, of least 50 centimeters deep that drain water fluxes during rain events. This type of erosion expression can not be eliminated through cropping techniques. (Rodrigues, 2003: Roose, 1996).

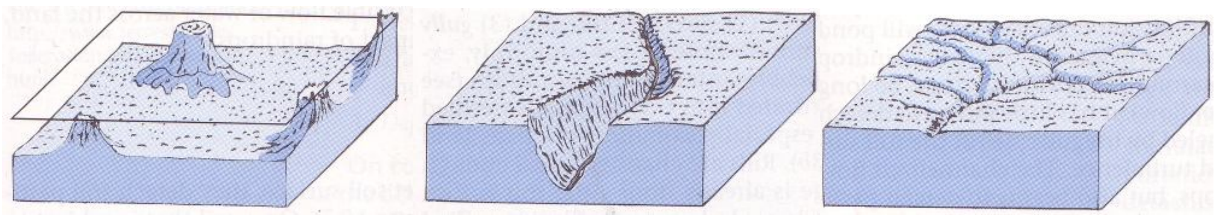


Figure 16. Different soil erosion expressions used as indicators. Taken and modified from Brady et al., 2004

These indicators of erosion were also used to classify them into erosion categories. To do this were combined three different classifications: F.A.O., (2006), El-Swaify et al., (1982) and Vigiak et al., (2005) from which were taken the classes, the descriptions and indicators respectively. This was done in order to count with a more detailed classification.

	Class	Description/indicator
S	Light	No apparent or light erosion/shallow exposure of roots and stones
M	Moderate	Moderate loss of topsoil generally and/ some dissection by runoff channels/widespread inter-rills sings and sporadic rills
V	Severe	Severe loss of topsoil generally and/or marked dissection by runoff channels/widespread rills.
E	Extreme	Complete truncation of the soil profile and exposure of the subsoil (B horizon) and/ deep and intricate dissection by runoff channels/gullies.

Table 6. Erosion Classification. Taken and modified from F.A.O., (2006), Swaify et al., (1982) and Vigiak et al., (2005)

4.2.2. Support Practice

For the evaluation of this section were evaluated conservation practices that according Li-Ling Li (1977) could reduce the erosive potential of runoff, trough their influence in runoff velocity, volume and drainage patterns such as: contour tillage farming, terracing systems and contour cropping (Smith and Wischmeier, 1978; Brady et al., 2004).

4.2.3. Cover and Management System

Related to cover and management systems were evaluated practices that could reduce the impact of rain drops on soil or affect the soil aggregates stability, such as: crop residues management, crop canopy management and tillage or plowing system (Smith and Wischmeier, 1978).

RESULTS AND DISCUSSION

5.1. Field assessment

In order to have a better understanding of erosion processes and its dynamics with soil classes, land uses and slope gradients in Pito Aceso, the micro-basin was stratified based on the presence of the erosion events found along different elevation. Thus the micro-basin was divided in domain A, B and C, going from 600 to 750, 750 to 950 and 950 to 1650 m.a.s.l. respectively, table 7

Table 7. Domains classification.

Domain	Elevation (m.a.s.l.)
A	600-750
B	750-950
C	950-1650

5.1.1. Soil erosion according Domains

5.2.1.1. Domain A

It was observed that most of area of the domain A was under perennial cropping, annual cropping and clean pastures. In terms of distribution, annual cropping is located within areas of very light, light or medium gradient, while perennial cropping, basically coffee and cassava, is located in areas of strong gradient while pastures are found in slopes of strong and very strong gradient.

Related to soil classes' distribution was identify the presence of Cambisols and Gleisols in plane areas, Argisols and Cambisols in slope of light and medium gradient and Cambisols and Latosols in slope of strong and very strong gradient; the relation of soil class and slope type was identified as followed: Argisols and Latosols were related to convex slopes and Cambisols to concave slope.

Within this domain were identity 6 point of erosion:

Case 1: Rills in Latosol in convex slope with very strong gradient under pastures.
Case 2: Rills in Latosol in convex slope with very strong gradient under pastures.
Case 3: On-process Gully in Cambisol in concave slope with strong gradient under pastures.
Case 4: On-process Gully in Latosol in convex slope with very strong gradient under pastures.
Case 5: Rills in Latosol in convex slope with very strong gradient under pastures.
Case 6: Rills in Latosol in convex slope with very strong gradient under pastures.

Most of the eroded areas within this domain occurred in **clean pasture** in strong and very strong gradient under Cambisols and Latosols, where were observed gullies and on-process gullies in Cambisols and rills and on-process gullies in Latosols. This difference in erosion expression is attributed to the higher erodibility of Cambisols against Latosols. In this sense Endres et al., 2006 and Inácio et al., (2007) also reported higher rates of soil erosion in pastures and soil degradation in gradient steeper than 25 % while Fereira et al., 2008 and Bono et al., 1996 attributed the higher soil losses and gullies presence in Cambisols to the high presence of sand and silt fraction (which makes Cambisols more susceptible to soil crusting); cattle overgrazing and the effects of tramping; the nature and micro-porosity of superficial and sub-superficial horizon which give this soils poor drainage and higher susceptibility to gully formation due to the rough relief.

When classifying this domains in terms of erosion, domain A could be categorized as an area of transition, from moderate to severe erosion, due to the presence of moderate loss of topsoil, marked dissection by runoff channels and widespread rills.

Figure 17. Case 1: Rills in Latosols in convex slope with very strong gradient under pastures.

Figure 18.Case 2: Rills in Latosols in convex slope with very strong gradient under pastures.

Figure 19. Case 3: On-process Gully in Cambisols in concave slope with strong gradient under pastures.

Figure 20. Case 4: On-process Gully in Latosols in convex slope with very strong gradient under pastures.

Figure 21. Case 5: Rills in Latosols in convex slope with very strong gradient under pastures.

Figure 22. Case 6: Rills in Latosols in convex slope with very strong gradient under pastures.

5.1.1.2. Domain B

The dominant land uses in B domain are late secondary forest and initial secondary forest followed by perennial cropping, annual cropping and abandoned pastures. In terms of soil classes in this domain was identity the presence of Cambisols and Latosols. The main differences between this domain and domain A is that most of the areas **with annual and perennial crops occur in areas with medium, strong gradient** while areas with strong of very strong gradient are mostly covered by forest with the exception of some annual and perennial cropping, clean and abandoned pastures Therefore is possible to see a reduction in the amount of cultured area due to slope gradient.

In this domain were identified 4 points of erosion:

Case 7: Rills in Cambisol in convex slope with very strong gradient under pastures.
Case 8: Rills in Cambisol in concave slope with very strong gradient under banana.
Case 9: Gully in Cambisol in straight slope with very strong gradient under pastures.
Case 10: Rills in Latosol in straight slope with very strong gradient under cassava.

The largest eroded area found in the study area took place within this domain, (case 9) Gully in small abandoned pasture in Cambisols with A horizon with high contends of sand in a very strong gradient. This high content of sand gives this Cambisols a low capacity for aggregates formation therefore low stability, making it very vulnerable to soil particles dissociation and removal trough runoff.

In the other two cases of erosion in cropping areas under very strong gradient, was an expected situation since cropping represents the most inadequate use for this area. In this sense Gianerini et al, 2008 reported the existence of evidence of the negative effects of banana and cassava on soil aggregates stability for the same region.

Domain B would be categorized as an area of moderate erosion due to the presence of moderate loss of topsoil and some dissection by runoff channels accompanied by widespread inter-rills sings and sporadic rills, outstanding annual and perennial cropping areas. This with the exception of case 9 which would be a case of extreme erosion due to the complete truncation of the soil profile and deep intricate dissection by runoff channels characterized by the presence of gully.

Figure 23. Case 7: Rills in Cambisol in convex slope with very strong gradient under pastures.

Figure 24. Case 8: Rills in Cambisol in concave slope with very strong gradient under banana.

Figure 25. Case 9: Gully in Cambisol in straight slope with very strong gradient under pastures.

Figure 26. Case 10: Rills in Latosols in straight slope with very strong gradient under cassava.

5.1.1.3. Domain C

The less dynamics in terms of land use and slope gradient is the C domain which is mainly covered by forest due the very strong gradient of slopes which limits agriculture activities. The dominant soil classes in this domains are Cambisols and Latosols with Humic A horizon. No strong sings of erosion were found within this domain which means that natural land cover represents the best option to protect rough relief against erosion.

Domain C would be categorized as an area of light erosion, due to the non apparent presence of soil erosion sings within this area.

5.2.2. Support practice

Out of the three support practices evaluated (soil tillage, terracing and contour cropping) in Pito Aceso, it was not observed the presence of mechanical soil tillage, this due to the very rough relief which difficults tractor operation. Situation that represents an advantage in terms of soil erosion risk reduction trough the reduction of breakdown of soil macro-aggregates thus keeping soil structure and its stability.

Relate to the other two practices, it was observed the presence of contour cropping for roses production (Rosa berberifolia Pall) in Cambisols in slopes of medium to strong gradient and for passion fruit (Passiflora edulis Sims) in slopes in Latosols of very strong gradient while it was observed agriculture in mini terraces for beans (Phaseolus vulgaris Lineo) production in Latosols with very strong gradient.

In case of contour cropping for roses production under cambisols in medium to strong gradient represents an apparent good practice in comparison to the others uses found under the same soil and relief conditions such as unmanaged pasture and annual cropping where sings of erosion were observed. This due that as a perennial crop the soil under roses does not require constant be tilled which maintain soil stability plus the protection offered by contouring cropping against runoff.

Meanwhile in the case the passion fruit under Latosols the implementation of support practice represents reinforcement in the reduction of the probabilities of soil loss occurrence in soils with relative low erodibility. In relation to beans production in terracing, it is significant to mention that even though it is a practice that reduce soil loss, it is not implemented consciously as a conservation measure by farmers but implemented as a method to facilitate agriculture such as condition of relief.

It is important to highlight that the fact in Pito Aceso predominates a familiar farming system practiced in small to medium plots, this facilitates the implementation of conservation measures, thus preserving soil quality and existing the possibilities to use the land for a longer period.

Figure 27. Rose production in contour cropping in Cambisol

Figure 28. Passion Fruit in contour cropping in Latosol

Figure 29. Beans in small terraces in Latosol

5.2.3. Crop and Cover Management

In relation to the three conservation practices (crop residues management, crop canopy management and tillage or plowing system) evaluated in this section, it was not observed the presence of mechanized tillage in none of the different land uses present in Pito Aceso micro-basin. This is due to the very rough relief which limits tractors operation.

In the case of the other two practices it was frequently observed in the field relative dense soil cover, presence of previous crops or weeding residues underneath the main crops for both annual and perennial crops; which according to Bertol et al., 2001 favors the continuous contribution of organic matter, which is fundamental for the maintenance of a good soil structure. In the other hand was also observed the presence of mix cropping or crop association especially for coffee, In this case depending of the stage of the coffee plants the canopy compensates the scatter canopy of cassava plants reducing the velocity and impact of raindrops, therefore reducing splash effects.

Along the three domains was observed the presence of different land uses in mostly tow types of soils, Cambisols and Latosols in strong and very strong gradient, which made obvious the effects of different land uses on the different soil classes. The uses associated to these soils classes were forest, clean pasture, annual crops such as cassava (Manihot esculenta), bean (Phaseolus vulgaris Lineu) and perennial crops such as passion fruit (Passiflora edulis Sims) , coffee (Coffea arabica Leneu) , banana (Musa acuminata Colla).

In the case of Latosols in one hand were found areas covered with forest and areas under cultures of passion fruit, bean, coffee and cassava, all of them cultivated under certain type of conservation measure in which cases were not identified serious sings of erosion processes. In the other hand were also found unmanaged pastures and some cassava plots cultivated without any conservation measure, where in the case of pastures was observed widespread inter-rill erosion, several rills and on-process gullies product of cattle trampling and in the case of cassava was observed the presence of rills and exposed soil (situation which enhance erosion process). **Therefore it is possible to say that in the case of Latosols under strong or very strong gradient would be necessary the implementation of conventional conservation measures in order to keep soil within a threshold where soil erosion does not take place under destructive means.**

In reference to Cambisols it was observed in one hand the presence of clean pastures under strong and very strong gradient, where in most of the cases was identified moderate to severe erosion expressions due to convergence of factors such rough relief, effects of trampling by cattle and high susceptibility to erosion. In the other hand were identified some areas under abandoned pastures, perennial crops such as roses and other areas under mix cropping of coffee and pumpkin, in cases where erosion processes where reduced due the higher protection offered to soil by this systems. However it was still observed the presence of sheet erosion in the case of mix cropping due to the scattered canopy of young stage crops.

Therefore it is possible to say that in the case of Pito Aceso unmanaged pastures represented the most inappropriate land use to practice in Cambisols and Latosol in slope with strong and very strong gradient and that in terms of soil cover and canopy management it presented a relative good management in both annual and perennial cropping. This with the exception of some cassava plantations in slope with strong and very strong declivities that in the cases of Latosols and Cambisols represent areas of high susceptibility to soil erosion, due to the disruption of soil stability during harvest period and the period of soil exposure after harvest and sawing of the new crop.

Figure 30. Crop association of Cassava and Coffee in Argisol

Figure 31. Coffee production with dense soil cover in Latosol.

Figure 32. Crop residues in Pumpkin plot.

5.2. Desk research

5.1.1. Land use and Slope gradient (Raster calculation)

As a result of the maps integration and raster calculation was observed that Pito Aceso micro-basin's landscape is mainly dominated by slopes of strong and very strong gradient, 85% of the total surface. This area is mainly covered by LSF and ISF, followed by CP and AP and less present AC and PC. The second most predominant landscapes are slopes of medium gradient with about 10%, covered by LSC, followed by ISF and AP, followed by AC, PC and CP. The less predominate landscape are areas of light and very light gradient that occupy the remaining 5%, which in case of light gradient were identified two main land uses: LSF and AC, and in the case of very light gradient was identified the predominance of AC in a relation of the 6:1 to PC. This is summarized in table 8.

Table 8. Slope gradient distribution.

Slope		
Gradient (%)		
	Percentage (%)	Hectares (ha)
Very light (1-6)	1.71	8.16
Light (6-12)	3.67	17.48
Medium (12-20)	10.26	48.87
Strong (20-45)	42.31	201.51
Very strong (>45)	42.04	200.19
Total	100 %	476.21*

*reaming 20.7 ha correspond to rocky outcrop, built area and clouds.

Land use	Slope gradient				
	Very light	Light	Medium	Strong	Very strong
Rocky outcrop	0.00	0.00	0.20	1.36	7.23
Constructed area	8.51	1.56	1.63	0.31	0.01
Annual	54.23	25.77	13.21	9.32	2.96
Perennial	9.71	6.98	7.83	9.39	2.03
LSF	8.32	28.78	30.69	39.11	60.13
ISF	6.10	16.70	20.80	17.80	14.53
Clean pastures	8.95	5.46	5.17	11.58	7.80
Abandoned pastures	2.93	12.34	19.66	10.15	4.62
Bared soil	1.23	2.40	0.81	0.98	0.60
Total	100%	100%	100%	100%	100%

Table 9. Slope gradient and Land uses.

Regarding to the recommended uses according slope gradient (Table 4), slopes within the very light category mainly under AC would fall under appropriate use, due to fact that planes areas are suitable for intensive agriculture due to the low risk to water erosion due the reduced impact of water runoff, controlled by the slope gradient. Situation that also facilitates the practice and increases the efficiency of soil amendments. In the case of Pito Aceso the possibility of soil erosion in these areas are even lower due to the fact that these areas are fragmented in small plots destined to horticultural production.

The same case would be for slopes within the category of light gradient where AC is the second bigger land use. The difference in this case is that, for AC in light gradient slopes, it is required the implementation of light soil conservation measures in order to fall in the category of appropriated use, which is the case of the study area where several conservation measures were identified (explained in section 5.2.2 and 5.2.3). In relation to the small fraction of medium gradient slopes covered by CP, they take place within bigger pastures mainly in slopes of strong gradient in this case it is evaluated as a whole unit within the strong gradient category.

For slopes of medium gradient there are areas which probably would be under inappropriate use, such as areas under AC (13%) if conservation measures such as fallow systems and conservation tillage are not implemented. As same as in the previous case the small fraction of CP is analyzed within the context of CP in slope of strong gradient.

In the case of slopes within the category of strong gradient, in one hand the most appropriate use beside forest would be PC (9% of the total area) as long as it is practiced under strong conservation measures such as rotation. In the other hand CP and areas under AC which occupied 11 and 9% respectively would represent areas of inappropriate use, due to the impact of these uses and strong gradient on erosive processes especially on runoff**. Thus slopes with strong gradient under CP and AC could be potential focus of water soil erosion if processes such as overgrazing and soil exposure in the case of annual cropping take place.**

Relate to the fifth category, slopes of very strong gradient due to their very rough relief it is mandatory to declare them as conservation area. However it is still found areas within this category areas under CP, AC and PC which as same as in the previous case represent areas with high potential of occurrence of water soil erosion.

Therefore is it possible to say that in terms of relief Pito Aceso micro-basin presents a very rough relief, which demands a careful land use planning, and the adoption of soil conservation practices and that in terms of possible focus of soil erosion due inappropriate land use the more vulnerable areas would be areas with slopes under CP and AC within medium, strong and very strong gradient . In all the case this work aims to assess the landscape of Pito Aceso as an entire entity, therefore it encourages the protection of areas declared as areas of mandatory preservation

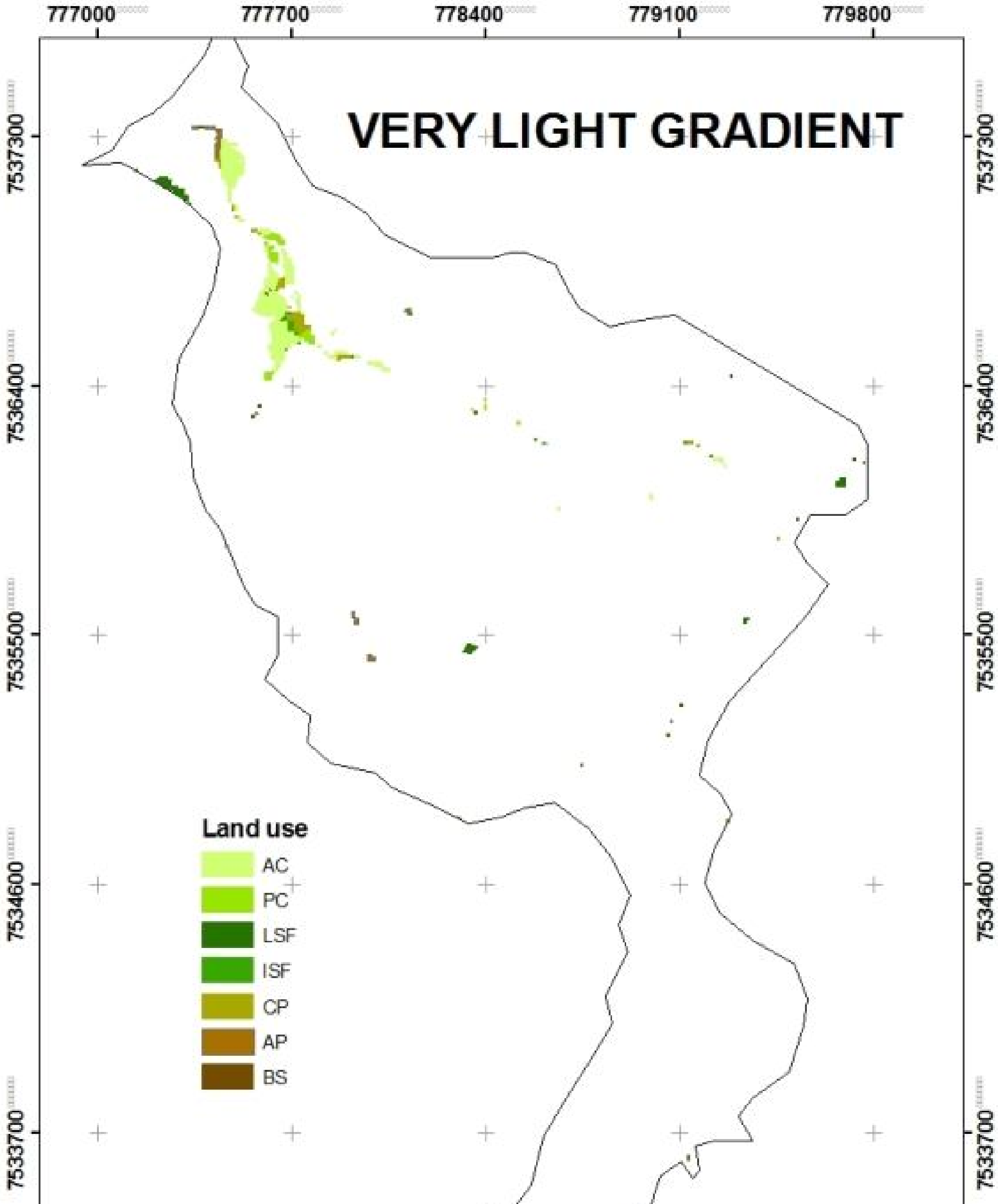


Figure 33. Very light gradient and its predominant land uses.

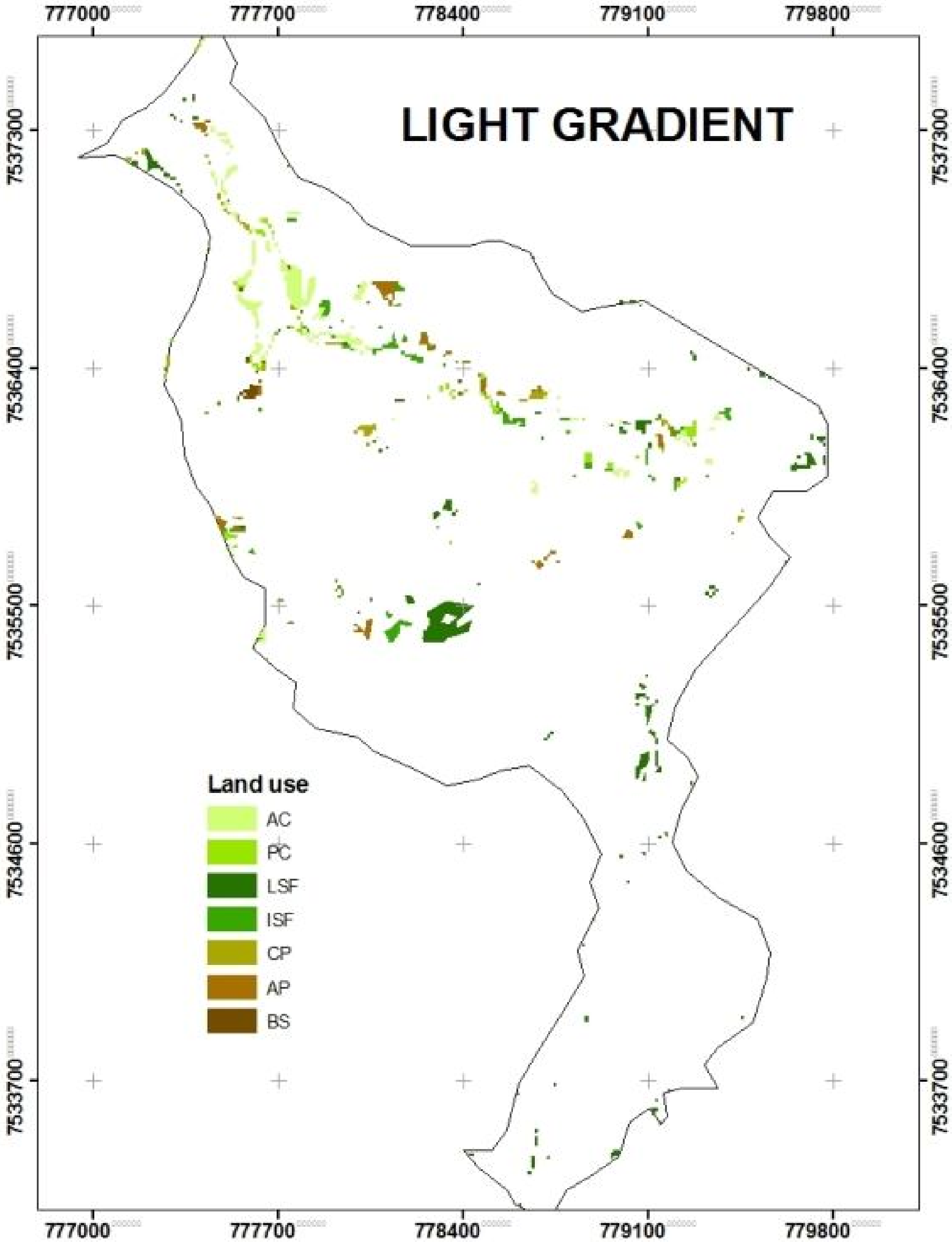


Figure 34. Light gradient and its predominant land uses

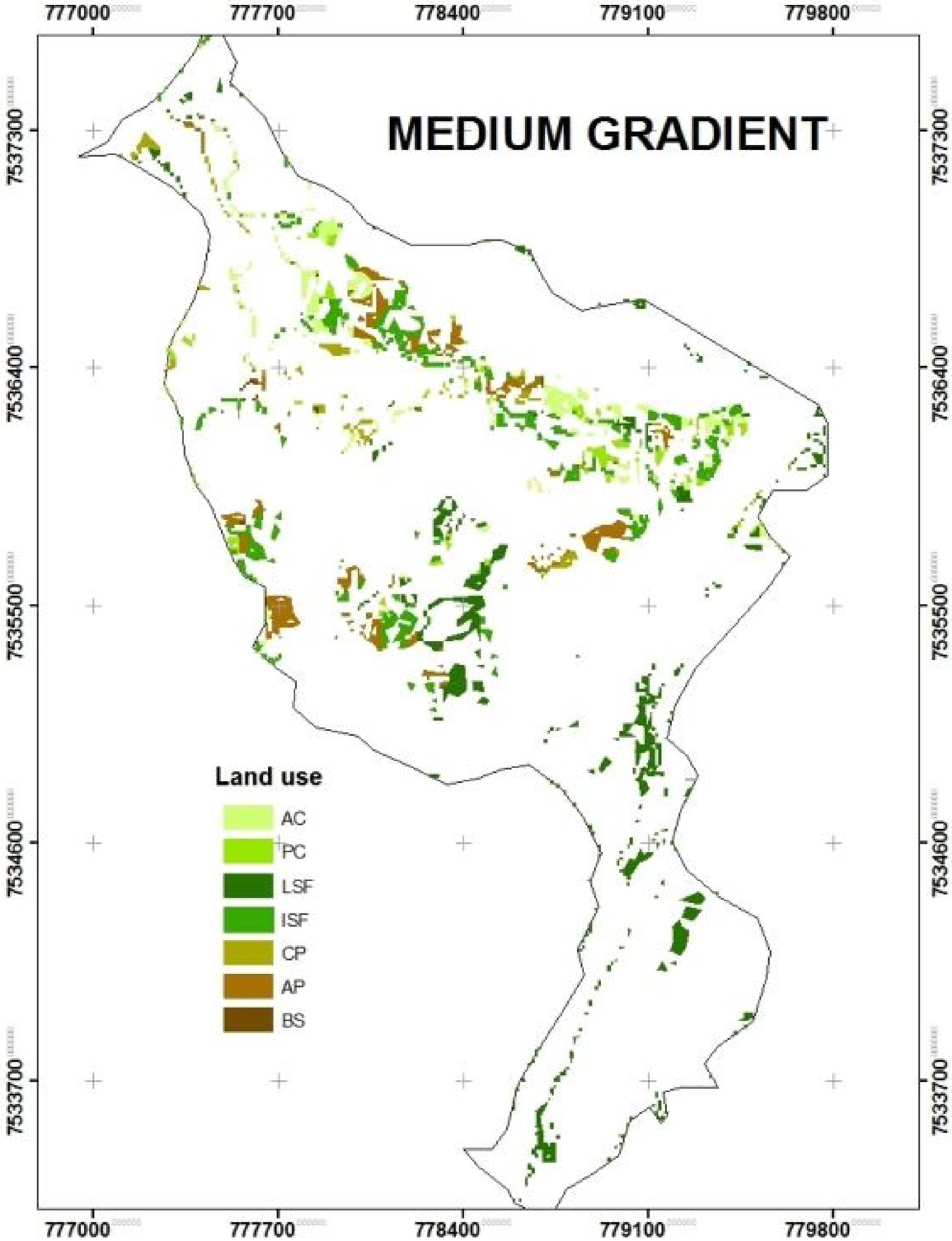


Figure 35. Medium gradient and its predominant land uses.

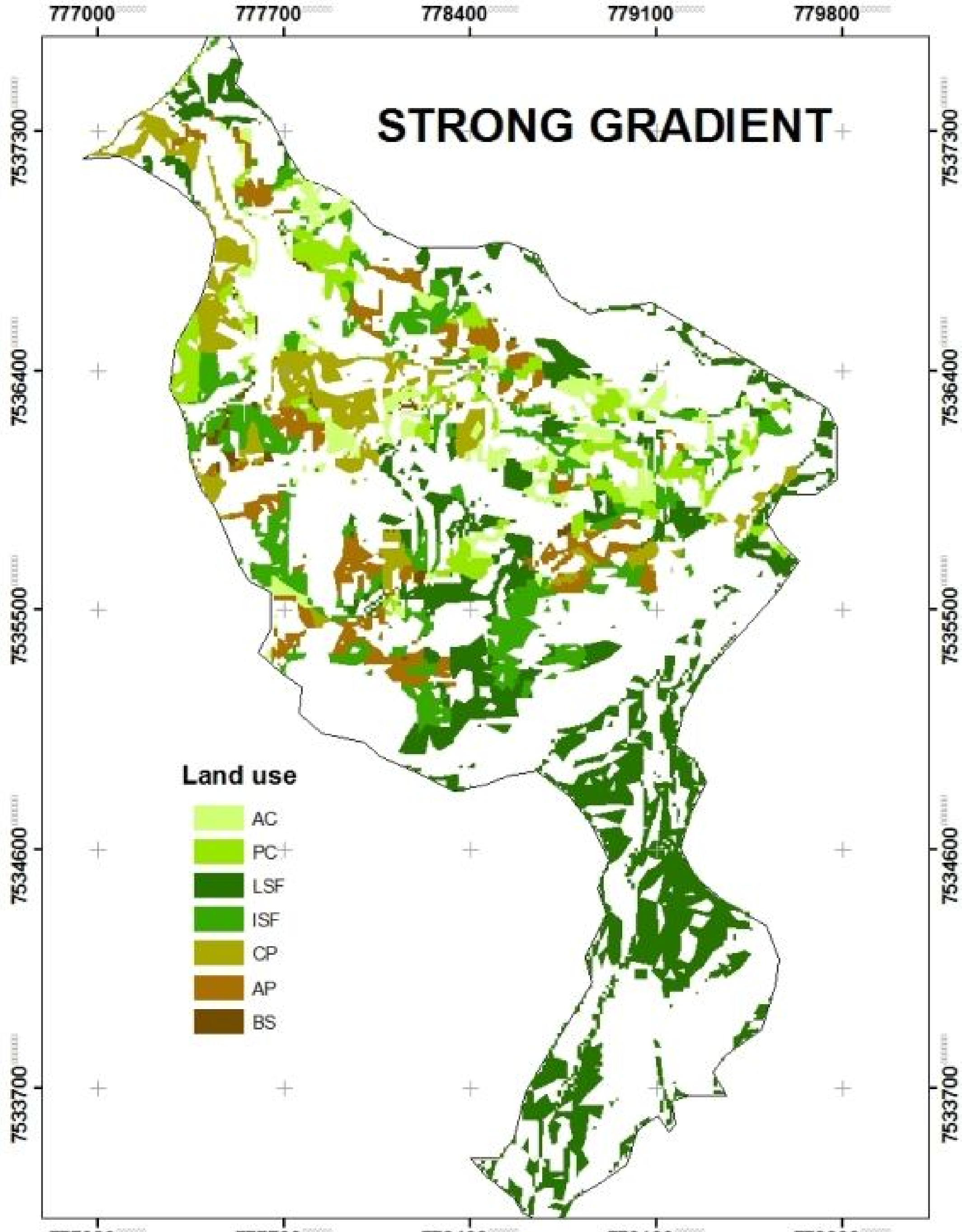


Figure 36. Strong gradient and its predominant land uses.

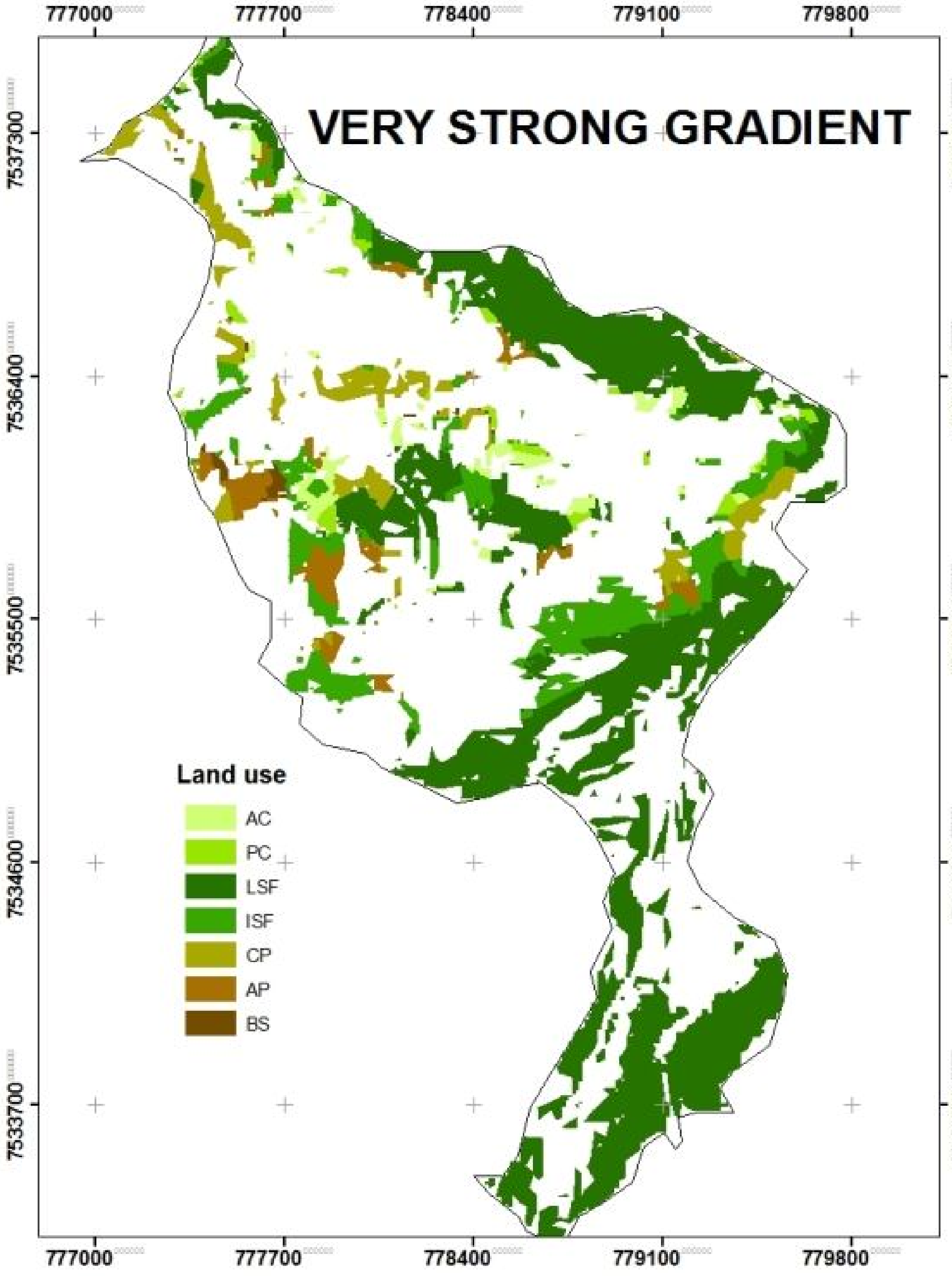


Figure 37. Very strong gradient and its predominant land uses.

5.2.2. Soil classes and Soil erodibility (K values)

Out the four soil classes found in the study area (Latosols, Argisols, Cambisols and Neosols), was just found the association of Cambisols and Latosols to erosive process, this is due to the distribution of soil class with the landscape of Pito Aceso Table 10.

According to the results from Bouyoucos equation the highest values for erodibility corresponded to Argisols and Cambisols and the lowest K values were presented by Latosols, Table 11.

In the case of Argisols were above the reported by Sa et al., 2004 who reported values of 0.032 t.ha.h/ha.MJ.mm for the State of Rio Grande do Sul, and bellow the values of 0.0438 and 0.0466 t.ha.h/ha.MJ.mm reported by Paes et al., 2004 and Manniguel et al., 2002 respectively, both for the estate of Sao Paulo. While in the case of Cambisols values obtained were also above the reported by Manniguel et al., 2002 for Cambisols Haplicos Distróficos of 0.025 and 0.034 t.ha.h/ha.MJ.mm. In the case of Latosols results matched with values presented by Paes et al., 2004 who reported K values for Latosols between 0.0134, 0.0173 t.ha.h/ha.MJ.mm for the State of Sao Paulo, but bellow the values reported by Neves et al., 2002 of 0.026 t.ha.h/ha.MJ.mm for a Cwa climate region.

This difference in soil erodibility is attributed to the presence in high clayey texture of Argisols and the difference in clay particles found among the superficial horizon A and the sub-surface Bt (B textural), which provoke the sealing of sub-horizons (EMBRAPA Floresta, 2009). According to Ker, 1998, Da Silva, 2005 and Tadeu, et al., 2003 the low values of erodibility in Latosols are attributed to higher degree of intemperism, low content of silt in relation to clay particles, uniform distribution of clay particle along the different horizons, higher concentration of Fe, Al that contribute to granular structure therefore higher stability of aggregates, higher flocculation, porosity and permeability. Case contrary of Cambisols which presents lower chemistry activity therefore lower concentration of cations, blocky structure, low soil depth, accentuated characteristic that make Cambisols unstable systems (Da Silva, 2005).

Table 10. Slope gradient and associates soil classes and land uses.

Slope		
Gradient	**Associated soil class**	**Associated land use**
Very Light	Cambisols and Gleisols	(AC>PC)>CP>LSF>ISF
Light	Cambisols in concave slopes/Argisols in convex	LSF>AC>ISF>AP
Medium	Cambisols in concave and Latosols in Convex	(LSF>ISF)>AP>AC>PC>CP
Strong		(LSF>ISF)(>CP>AP)(>AC>PC)
Very Strong	Latosols and cambisols with deep A Humic horizon	(LSF>ISF)(>CP>AP)(>AC>PC)

Table 11. Soil erodibility according Bouyoucos equation.

soil class	Erodibility A	Erodibility B
Latossolo Vermelho Distrófico típico	0.022656	0.017288
Latossolo Vermelho Distrófico cambissólico	0.018902	0.013419
Latossolo Amarelho Distrófico húmico	0.014390	0.008868
Argissolo Vermelho Eutrófico abrúptico	0.039261	0.025088
Argissolo Vermelho-Amarelho Distrófico típico	0.018986	0.012321
Argissolo Vermelho Eutrófico tipico	0.027736	0.015641
Cambissolo Háplico Tb Distrófico típico	0.034643	0.035045
Cambiossolo Háplico Tb Distrófico latossólico	0.034843	0.025211
Cambissolo Húmico Distrófico típico	0.020030	0.019851
Cambissolo Háplico Tb Distrófico típico	0.039261	0.039261
Neossolo Litólico Húmico típico	0.070000	

If erosion is assessed in terms of K factor and slope gradient it is possible to say that the possibilities of erosion occurrence are higher in Cambisols in slope with medium, strong and very strong gradient than in Latosols in the same landscape due to the higher K values of Cambisols. The possibilities would be enhanced or reduced by the type of land use given to the slopes; situation which was confirmed with the enhancing of erosion in areas under unmanaged pastures and reduction in areas under managed perennial cropping and forest.

6. CONCLUSIONS

According to the number of presence of erosion expressions in relation to the elevations Pito Aceso was divided in three domains or landscape units: domain A, B and C, going from 650 to 750, 750 to and 950 and 950 to 1650 m.a.s.l. respectively. Domain A presented six erosion events mainly in slope under pastures with strong and very strong declivities, the dominant erosion expressions were rills and on-process gullies. Therefore this domain was categorized as an area with moderate to severe erosion. Meanwhile domain B presented four erosion events mostly in slope very strong gradient under perennial and annual cropping, in this case predominated sheet erosion and rills erosion. Thus it presented moderate erosion. In the case of domain C were not identified strong sings of erosion processes, therefore categorized as an area of light erosion.

This reduction in presence of erosion expressions along the three landscapes units was related to increment of forest presence and reduction of agricultural activities in relation with the increment of slope steepness. In the case of Pito Aceso, plane areas and areas with light gradient were dominated by AC under Cambisols and Argisols. This tendency decreased in steeper areas where the dominated land uses were CP and PC in Latosols and Cambisols. Meanwhile the steepest areas are covered mainly by forest.

The Erosive process identified in Pito Aceso take place mostly in CP in Latosols and Cambisols in slopes with strong and very strong gradient. In the case of Cambisols, were observed mostly on-process gullies and some rills while in Latosols were observed rills and some inter-rills erosion. This difference in soil erosion expressions was attributed to the poor soil development, better structure, higher micro-porosity and higher contents of sand and silt particles, consequently higher susceptibility to aggregates disassociation and soil crusting of Cambisols in comparisons to Latosols.

Relate to the cases of erosion in AC and PC areas, predominated rills and the causes of these were more related to inappropriate use in function of slopes gradient than to inappropriate management as is the case of CP

In reference to the impact of the different land uses on soil stability, CP presented the highest impact on soil stability trough the disruption of superficial horizons with rills and on-process gullies. In the second place areas under AC and PC, followed by areas covered with forest. The implementation of conservation measures, in case of annual and perennial cropping, helped to preserved soil stability trough the reduction of runoff, impact of raindrop and addition of organic matter into the soil. this was confirmed with the absence of strong sings of erosion in these areas. Some exceptions were observed in some cassava plantations in slope with strong and very strong declivities, which in both cases Latosols and Cambisols represented areas of high susceptibility to soil erosion due to the disruption of soil stability during harvesting and the period of soil exposure after harvest and replanting of the new crop.

In Pito Aceso the more vulnerable areas to erosion are AC and CP in slope with very strong, strong and medium gradient, followed by areas under PC in strong and very strong gradient. All these especially in Cambisols and Latosols.

In general Pito Aceso presents a rough relief which demands a careful land use planning and the adoption of soil conservation measures and that the presence of familiar farming has reduced erosion processes by facilitating the implementation of conservation measures, mostly in annual and perennial cropping areas.

7. RECOMMENDATIONS

1. To carry out a survey in the study area to evaluated the perception of farmers about erosion, in order to be able to generate solutions hand by hand with the farmers. especially in areas under pastures affected by severe and moderate erosion.
2. To promote the implementation the Silvo-pastoral systems, since the use of perennial species appeared to be, after forest, the system that offer the best protection to soils in the region.
3. To carry out an assessment about suitable areas for eucalyptus plantations within Pito Aceso, since eucalyptus has been planted without any supervision. Therefore, there exist the possibilities to alter even more the already disturbed landscape.
4. To do an up-date of the land use change map for the region, since it was observed the conversion of forested areas into agricultural land, situation which could be enhancing erosion processes.
5. To do a soils' evolution analysis in relation to the land use change and determine their different susceptibility to erosion, to propose possible sceneries and alternative of adaptation to face global warming.
6. To analysis the impacts of roads in erosion processes in the region.

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