



Soil Erosion and Conservation in Brazil

Erosão e Conservação de Solos no Brasil

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Abstract

Brazil covers 8,547,403 km² and is divided into five regions (Northern, North Western, Central Western, South Eastern and Southern). The diversity of climate, geology, topography, biota and human activities have contributed to the considerable diversity of soil types and thus soil erosion problems. National soils can be classified into 12 classes. These are: Oxisols (38.7%), Alfisols (20.0%), Inceptisols (2.7%), Mollisols (0.5%), Spodosols (1.6%), Gleysols (3.7%), Aridisols (2.7%), Entisols (14.5%), Vertisols (2.0%), Ultisols (1.8%), Plinthosols (6%) and Alisols (4.3%). The erodibility of these Soil Orders is reviewed and is mainly related to soil texture. Sands and loamy sands are especially erodible. Soil erosion patterns are complex, being influenced by rainfall erosivity, soil erodibility, topography, land use and management characteristics. Urban areas have specific erosion problems and there are illustrated using a case study from São Luis (north-east Brazil). Soil erosion rates can be excessive, in some cases exceeding 100 tonnes per hectare per year. Particularly serious soil erosion is associated with six regions. These are north-western Paraná State; the Central Plateau, in the Centre Western Region; Western São Paulo State; the Paraíba do Sul middle drainage basin, in Rio de Janeiro State; *Campanha Gaúcha* in Rio Grande do Sul State and *Triângulo Mineiro*, in western Minas Gerais State. Examples of effective soil conservation are presented, using case studies from both Paraná and Santa Catarina States. Integrated management of drainage basins offers a promising way forward for effective soil conservation in Brazil.

Keywords: Soil erosion; soil conservation; soil mapping

Resumo

O Brasil ocupa 8.547.403 km² e está dividido em cinco regiões (Norte, Nordeste, Centro-Oeste, Sudeste e Sul). A diversidade climática, geológica, topográfica, da biota e das atividades humanas tem contribuído para a grande diversidade de tipos de solo, assim como para os problemas de erosão. Solos nacionais podem ser classificados em 12 classes. Estes são: Latossolos (38,7%), Argissolos (20,0%), Cambissolos (2,7%), Chernossolos (0,5%), Espodossolos (1,6%), Gleissolos (3,7%), Luvisolos (2,7%), Neossolos (14,5%), Vertissolos (2,0%), Planossolo (1,8%), Plintossolos (6%) e Alissolos (4,3%). A erodibilidade dessas classes de solo foi revisada e relacionada principalmente à textura. Solos arenosos e franco-arenosos são especialmente mais susceptíveis à erosão. Os padrões de erosão são complexos, sendo influenciados pela erosividade da chuva, erodibilidade do solo, topografia, uso e manejo do solo. As zonas urbanas têm problemas específicos de erosão e estes são ilustrados através de um estudo de caso de São Luís (Nordeste do Brasil). As taxas de erosão são significativas, sendo em alguns casos superiores a 100 toneladas por hectare por ano. A erosão é particularmente grave associada com seis regiões: noroeste do Paraná, Planalto Central, Região Centro Oeste, Oeste do Estado de São Paulo, médio curso da Bacia do Paraíba do Sul, no Estado do Rio de Janeiro; na Campanha Gaúcha, no Rio Grande do Sul e no Triângulo Mineiro, Estado de Minas Gerais. Exemplos de conservação do solo são apresentados por meio de estudos de caso no Paraná e Santa Catarina. A gestão integrada de bacias hidrográficas oferece uma maneira promissora para a conservação do solo em vigor no Brasil.

Palavras-chave: Erosão dos Solos; Conservação dos Solos; Mapeamento Pedológico

1 Introduction

Soil erosion and land degradation is a global problem and poses a major problem in Brazil. The hazard affects both urban and rural areas within the extensive national territory (8,547,403 km²) (Figure 1). In turn, these problems have serious environmental impacts and pose socio-economic problems. It is important that the soils are conserved, for the present and future generations. Although erosion is a natural phenomenon, often human activity accelerates erosion processes. Soil erosion on US agricultural soils causes the loss of an average of 30 tonnes per hectare per year (t ha⁻¹ y⁻¹); some eight times quicker than rates of soil formation. A survey by Embrapa (the Brazilian Ministry of Agriculture) suggested the situation in Brazil is often worse.

According to Goudie & Boardman (2010) “*it is quite clear that the major areas of intense erosion are associated with both human and natural factors.*” Boardman (2006) suggested the following countries and regions are global erosion ‘hotspots:’ the Loess Plateau of China, Ethiopia, Swaziland and Lesotho, the Andes, South and East Asia, the Mediterranean basin, Iceland, Madagascar, the Himalayas, the Sahel of West Africa, the Caribbean and Central America. We propose Brazil is also an erosion ‘hotspot.’

Brazil is characterized by a great diversity of soil types, corresponding to a wide variety of relief forms, climates, parent materials, vegetation cover and biota. Diverse pedogenic processes thus facilitate the pedogenesis of many soil types. Related to this great diversity, Brazil has its potentialities and limitations, in terms of land use. This diversity is enhanced by regional differences in terms of settlement, land use and development.

Brazil can be divided into several regions. These include the Northern (or Amazon) Region. The Region is characterized by plains and low plateaux, a tropical climate, perennial high temperatures, high humidity, deep and highly weathered soils, high acidity and low natural fertility. These soils have low production potential, especially when they are poorly managed.

The North Western Region has diverse climates, which vary from the humid and warm, near the coast, to semi-arid (warm and dry), in the interior. There is a semi-humid transition area between these two areas. Generally, soils have medium to high natural fertility, and are usually shallow, due to the relatively low weathering rate.

The Central West Region has a vast plateau, caused by prolonged erosive processes during geological time, called the Brazilian Central Plateau. The regional characteristics include the tropical climate, with two distinct seasons: one humid and another dry (approximately six months of each one); and extensive area with deep, well drained, acid soils with low natural fertility. However, these soils have potential and can be improved with the application of lime and other organic and chemical fertilizers. Once these treatments have been carried out, the region generally has a favourable relief for mechanized agriculture.

The South Eastern Region is characterized by plateaux and mountain ranges, which reach up to 2,000 m altitude. The climate is tropical, with hot summers on the lowlands and more temperate conditions on the mountain ranges and plateaux. Soils are generally deep, well developed and have low fertility (Embrapa, 2002).

The Southern Region has many soils developed on varied parent materials, including basic rocks and varied sedimentary rocks. These produce very diverse landscapes. The climate is sub-tropical with very well defined seasons. The predominantly fertile soils have high potential for agro-pasture (Embrapa, 2002).

This overview of Brazilian soils, in terms of the five great Regions, is fundamental, as these regional differences play key roles for environmental differences, which affect climatic, geomorphological and pedological domains. In turn, these affect agricultural potential and soil erosion characteristics throughout Brazil.

2 Soil Types and Erosion in Brazil

The eco-environmental diversity of Brazil promotes diverse soil types, which are integral components of these ecosystems and form essential natural resources. Based on the Soil Maps of Brazil (Embrapa, 1981) and the Brazilian Soil Classification System (Embrapa, 1999) there are 12 mapped national soil classes (Figure 2).

The Great Classes can be subdivided into different types, according to the main characteristics. Soil properties and characteristics are outlined, as well as their percentage in terms of spatial cover.

Oxisols are encountered in forests (dense, open and with palm trees) and *cerrado* (a form of

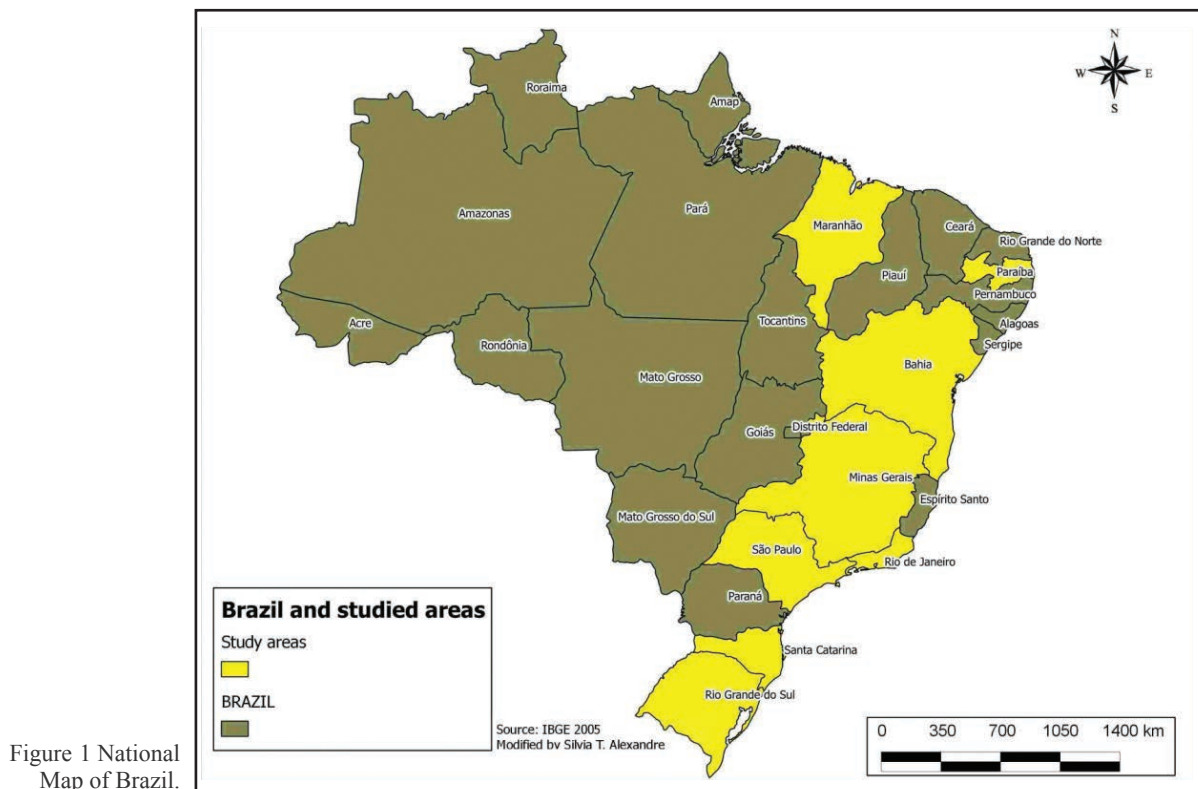


Figure 1 National Map of Brazil.

savannah), on relief which varies from flat to very hilly (Guerra & Botelho, 2012). They result from intense weathering of parent materials, including rocks and pre-weathered sediments. Clay fractions are usually in the latter stages of weathering (consisting of kaolinites (caulinites) and iron (Fe) and aluminum (Al) oxides). The sand fraction is dominated by minerals very resistant to weathering (Embrapa, 2002). Soil texture ranges between loamy to very clayey. Oxisols are generally deep, porous and permeable, with little difference in clay content in deep horizons. They usually possess low natural fertility. They have a high occurrence in Brazil, occupying 38.7% of national territory and are widely distributed. There are several types of Oxisols and they differ in terms of their colour, natural fertility, oxide contents and texture (Figure 2).

Alfisols characteristically have high clay content in the B horizon, but their properties are very heterogeneous. They are well structured, with variable depth and are usually coloured red to reddish yellow. Topsoils range from sandy to clayey textures and their subsoils are loamy to very clayey. In Brazil, the presence of caulinite is the main diagnostic mineralogy.

Alfisols occupy ~20.0% of Brazil and occur throughout the country. If one compares Alfisols with

Oxisols, the former tend to occupy more dissected relief. They are called Bt horizon soils, due to the concentration of clay in B horizons, increased by illuviation or lateral translocation. Thus there are considerable differences in clay percentage, between A and B horizons, usually with a transition from a sandy A horizon to a clayey B horizon. This may impede water infiltration, thus decreasing profile permeability.

Inceptisols are characterized by the heterogeneity of parent materials, landscapes, and climatic conditions; therefore their properties vary considerably. The main common characteristic is the incipient evolution stage of sub-surface horizons. Often rock fragments are embedded within the soil matrix and primary non-weathered minerals are common (Embrapa, 2002). They occupy ~2.7% of Brazil, and are widespread. Individual soil units tend to be small and usually concentrated on the foot-slopes of mountain ranges. These include Serra do Mar, which stretches from south-east to south Brazil, and Serra da Mantiqueira, in the South Eastern Region (Oliveira *et al.*, 1992). Inceptisols with high natural fertility are present in the North Eastern Region and Acre State (northern Brazil).

Mollisols have high soil organic matter (SOM) contents and thus have dark coloured A

horizons. Typically, they have very high clay activity in the subsoil, with the presence of vermiculites and/or smectites. They are well-structured and have high base saturation. They are moderately acidic to highly alkaline and have high natural fertility (Embrapa, 2002). These soils occupy only 0.5% of Brazil and are located mainly in two areas: part of Rio Grande do Sul State (Southern Region) and part of Bahia State (North East Region).

Spodosols (usually described as Podzols in the international literature) are mainly sandy, with accumulations of SOM and Al in deep profiles. They are very poor acidic soils, having high extractable Al contents, compared with other basic ions. They cover ~1.6% of Brazil and are widely distributed, especially along the coastal plain, mainly in Bahia, Sergipe, Alagoas, Rio de Janeiro and Rio Grande do Sul States and in Western Amazonia (Embrapa, 2002).

Gleysols occupy ~3.7% of Brazil, occurring usually on low depressed areas and, therefore, they are usually wet, unless artificially drained. They normally develop under recent sediments, along the rivers and on alluvial-colluvial materials, subject to hydromorphism, in low and flat areas (Embrapa, 2002). Thus, they are widespread in Brazil, especially where the water table is very close to the soil surface during most of the year. They are poorly drained and shallow, being usually acidic with high clay contents and low silt and sand contents (Guerra & Botelho 2012). Besides occurring in all wet areas of Brazil, they are in many areas of the Amazon basin, Goiás and Tocantins States, along the River Araguaia, and along the River Paraíba do Sul in Rio de Janeiro and São Paulo States.

Aridisols are mainly in the semi-arid zones of the North Eastern Region. They occupy ~2.7% of Brazil, with high natural fertility and high capacity to retain exchangeable ions (high activity clay) and high capacity for nutrient retention in subsurface horizons, underneath the A horizon. A horizons are typically shallow, with low SOM contents and low to medium capacity to retain nutrients (Embrapa, 2002).

Ultisols typically they have sandy topsoils, contrasting with sub-surface horizons with high concentrations of clay. These subsoil horizons harden (indurate) on drying and thus they have low permeability and are poorly drained (Embrapa, 2002).

They are present in *Pantanal Matogrossense*, Mato Grosso State and Rio Grande do Sul State (Oliveira, *et al.*, 1992), Amazonas, (Vieira, 1988) and Rio de Janeiro State (Silva & Mafra, 1991). They occupy 1.8% of Brazil and present visible signs of hydromorphism, due to their low permeability and because they are frequently situated on flat areas.

Entisols are poorly developed soils and occupy ~14.5% of Brazil. Their main characteristic is that they are sandy or sandy loam soils (Guerra & Botelho, 2012). They are formed mainly in sedimentary deposits and are widespread in Brazil (Embrapa, 2002). They are along many rivers developed in alluvium. They are also on mountainous areas and are very shallow (usually <50 cm deep) and are usually coarse textured, on top of rocky parent material. Entisols are found on extensive areas of São Paulo, Mato Grosso, Mato Grosso do Sul, Bahia, Pará and Maranhão States. Here the Entisols are deep (≤ 200 cm) and they are very well drained.

Vertisols occupy ~2.0% of Brazil (Figure 2). They are greyish to black, without significant differences in clay contents between topsoil and subsoil horizons. Nevertheless, the main characteristic is the pronounced change in moisture content, due to the presence of expansive clays, creating extensive cracks on soil surfaces in dry periods (Embrapa, 2002).

They occur mainly in the semi-arid areas of the North East, swampy areas of Mato Grosso State (called *Pantanal Matogrossense*) and in Bahia State around the State capital of Salvador, an area called *Recôncavo Bahiano*. They have high chemical fertility, but present problems in terms of their physical properties. Vertisols are poorly drained, presenting low porosity, especially in C horizons (Guerra & Botelho, 2012).

Plinthosols are encountered in very specific environmental conditions, where there is very low water flow, or frequent soil wetting (Embrapa, 2002; Guerra & Botelho, 2012). They accommodate soils that contain plinthite (an iron-rich humus-deficient mixture of kaolinitic clay with quartz and other constituents). They are known as groundwater laterite soils (*lateritas hidromórficas*) in Brazil. They cover ~6.0% of Brazil and are widespread, especially in lowlands, gently sloping areas, alluvial areas, depressions, river terraces and along some river banks. Therefore, these soils are very common in the Amazon basin, *Marajó* Island, Amapá, Maranhão, Tocantins and Goiás States and *Pantanal*

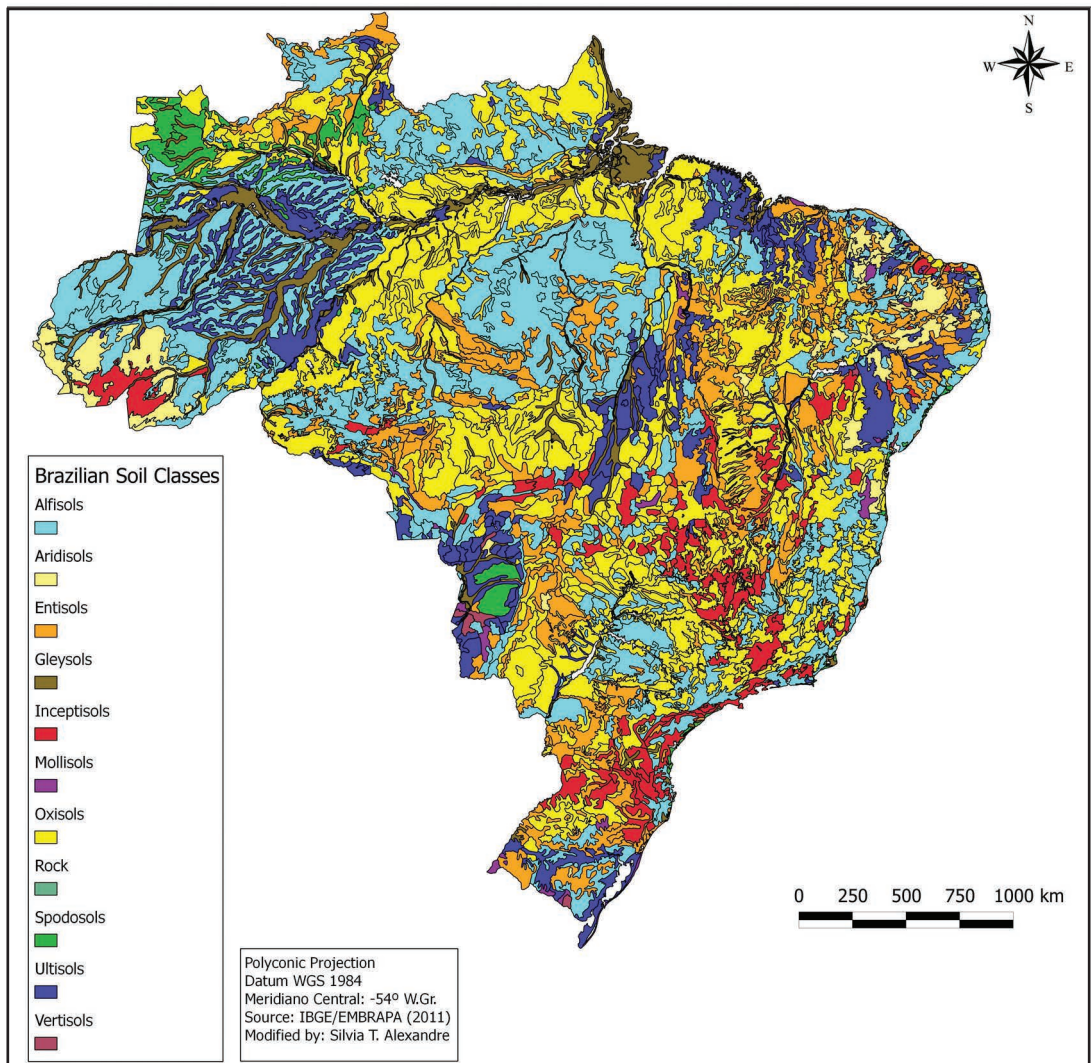


Figure 2
Soil Map of Brazil
(Based on US
Taxonomy).

Matogrossense (Mato Grosso State). All these soils are situated on low-lying flat lands. They are mainly acidic and have low nutrient reserves (Embrapa, 2002).

Alisols are poorly drained soils with a dense subsurface clay layer, which causes relatively high concentrations of Al ions in the rhizosphere. They cover 4.3% of Brazil and have low natural fertility (Embrapa, 2002). These soils are acidic and in some there is a significant increase in clay content in deeper horizons. They are distributed in sub-tropical Brazil: Paraná, Santa Catarina and Rio Grande do Sul States, but they also occur in tropical environments in western parts of the Amazon basin.

Histosols (organic soils) occur in Brazil, but they are in relatively small, widely distributed areas. Thus, scale issues preclude their inclusion on the National Soil National Map. Histosols are present on

some mountain ranges at ≥ 800 m altitude. Lowland Histosols are present within some drainage basins, including the Amazon, São Francisco and Paraíba do Sul basins. Depth of organic material is ≤ 80 cm, they have very low bulk densities (usually < 0.8 g/cm³) and they are poorly drained, due to the water retentive properties of the organic matter. The rest (1.5%) of national territory is covered either by water or rock outcrops.

2.1 Soil Erosion and its Impacts

Although there are several agents of erosion, water is the most important one. Cultivation can promote soil erosion, due to ploughing and harvesting, which moves soil down slopes. These erosion processes occur in Brazil, with water being the main erosive agent, causing serious problems, both where the processes occur (on-site) and off-site.

Off-site affects include river and reservoir siltation and water pollution. For instance, the total amount of sediment deposited into Itaipu reservoir was estimated at ~12.5 million tonnes by 1982 (Derpsch *et al.*, 1991). Scientists are trying to predict these geomorphological processes, in order to avoid or minimize negative environmental impacts. These include losses of both natural resources and finances, due to the costs of decreased soil productivity and the funds which need to be invested by local authorities and farmers to clear sediments and prevent erosion. Hufschmidt & Glade (2010) stressed the importance of adopting engineering measures to conserve soils.

Soil erosion rates have been investigated in different parts of the world and data from USDA (1994) has estimated a global mean of 14 t ha⁻¹ year⁻¹, with 9-11 t ha⁻¹ year⁻¹ being considered unacceptably high. Soil erosion rates in Brazil are highly variable and depend on several factors. These include soil types and their associated properties, the rainfall regime, with generally higher erosivity during summer, frequent low vegetation cover, long steep slopes with convergent flows and land mismanagement. The importance of land mismanagement has been particularly emphasized in Brazil (Guerra & Botelho, 2012).

In places erosion rates exceed 20 t ha⁻¹ y⁻¹ (Embrapa, 2002). For instance, erosion was estimated to average ~40 t ha⁻¹ y⁻¹ over 6 million hectares of cultivated land in Rio Grande do Sul State (Schmidt *et al.*, 1989). In Paraná State, the average was 15-20 t ha⁻¹ y⁻¹ on agricultural fields under intense mechanization (Paraná, 1994). Figure 3 shows the susceptibility of soils to water erosion, where susceptibility is classed as:

- Very low (there is very little risk of water erosion).
- Low (there is minimal risk of water erosion).
- Medium (there is some risk of water erosion, but depending on soil properties, rainfall erosivity and land use and management, this risk may be increased).
- High (depending on soil classes, rainfall erosivity, and land use and management, there is a high probability of excessive water erosion).
- Very high (there is a very high probability of very excessive water erosion). Thus, on these soils, there should be no forest clearance or

arable soil use. These areas are very sensitive to soil erosion and they should be maintained as Conservation Units. According to Brazilian Legislation, Conservation Units are protected areas. In some, no economic activity is permitted, whereas in others some economic activity is permitted, but only with official government permission.

In São Pedro drainage basin, Macaé Municipality, Rio de Janeiro State, erosion was estimated at 102 t ha⁻¹ year⁻¹, on sandy loam Oxisol and Inceptisol pasture soils, largely due to gully erosion (Loureiro, 2013). This is a rainy area, with an average annual precipitation of ~1,800 mm, concentrated during summer months (December-March). Soil erosion assessment in this area shows the role of land use and management in provoking accelerated erosion, especially gully erosion over recent decades (Figure 4).

In São Luís City (Maranhão State), North Eastern Region, urban gully erosion is severe. Erosion has been monitored using periodic surveys of gully morphology.

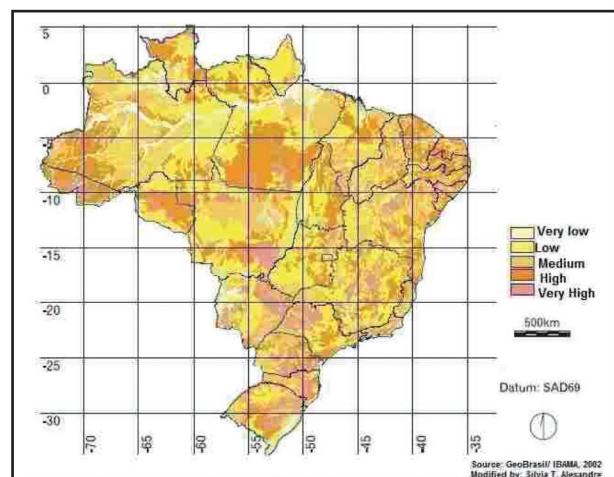


Figure 3 Simplified soil erosion by water map of Brazil.

Between 2000-2008, in Sacavém District, gully retreat totalled 4 m, equivalent to mean of 0.5 m per year (Guerra *et al.*, 2010). São Luís, like many other Brazilian cities, has experienced rapid population growth in recent decades, which has created a series of socio-economic and environmental problems, including accelerated soil erosion. Sacavém is one of these communities where natural and human factors contribute to severe gully erosion. Rapid population and urban growth has

intensified problems, compounded by poor planning and improper soil use (Figure 5).

Developments at the Sacavém gully can be monitored on the LAGESOLOS (Laboratory for Environmental Geomorphology and Soils Degradation of the Federal University of Rio de Janeiro) web site (Figure 6).

In Paraíba State (North Eastern Brazil), in the small (5.73 km²) experimental drainage basin of the Guaraíra River, between Alhandra and Pedras de Fogo Municipalities, taking into account two different years (1974 and 2011), erosion rates were >20 t ha⁻¹ y⁻¹. Particularly high erosion rates were found on bare soils and sugar cane plantations. Land use and management played a critical role in causing such high soil erosion rates (Costa & Silva, 2012).

Generally, the highest soil erosion rates in Brazil occur where vegetation has been cleared without conservation measures. This is the case of the Campinas River Catchment, in Joinville Municipality, Santa Catarina State, Southern Brazil. Some 93% of the study area lost 1-3 t ha⁻¹ y⁻¹ of soil from areas under native forests and agriculture with effective conservation measures (Guimarães *et al.*, 2011). Nevertheless, very high soil losses were measured and were associated with rural roads and urbanized areas with bare soil. On steep (10-35°) slopes, rates can exceed 200 t ha⁻¹ y⁻¹ (Guimarães *et al.*, 2011).

Intense soil erosion also occurs in Bahia State (North Eastern Region), in the Colonia River Catchment, in Itapetinga Municipality. Soil loss was estimated to be a mean of 47 t ha⁻¹ y⁻¹ for the 27 years between 1975-2002 (Silva *et al.*, 2011). Measurements of soil loss from forests and protected areas within the same catchment show total losses were 9-20 t ha⁻¹ y⁻¹.

Although there are many areas in Brazil where soil erosion occurs, six regions merit particular discussion (Guerra & Botelho, 2012). The first one is north-western Paraná State on Oxisols and Alfisols, where accelerated erosion started in 1950. This was due to several factors, including vegetation clearance, followed by disorganized urban growth and soil mismanagement on coffee, cotton and maize plantations and on cattle rangelands. These developments degraded soils in several municipalities of this region.

The second one is the Central Plateau, in the Centre Western Region, as well as some parts of the



Figure 4 Gully erosion in São Pedro drainage basin, Macaé Municipality, Rio de Janeiro State in April 2011 (Photo by Maria do Carmo Oliveira Jorge).

South Western Region, mainly on Oxisols, Alfisols, Entisols and Inceptisols. The gentle topography of those areas facilitate mechanized agriculture, which increases soil compaction (i.e. increased soil bulk density) and thus provokes runoff and high soil erosion rates. The rainy season, concentrated in less than six months, with an average ~1,500 mm of rain, is another contributory factor.

The third area is Western São Paulo State, which corresponds to 40% of State territory. The main soil classes are Oxisols and Alfisols with sandy loam textures. There are many gullies in the area, some of them >1 km long, ≤50 m wide and ≤30 m deep. The intense soil erosion causes problems for agriculture, because of the loss of soil fertility, but also due to off-site effects, especially siltation in rivers and reservoirs. Once more, land use and soil mismanagement are the main reasons for land degradation in this region.



Figure 5 Land rehabilitation in gullied area in São Luís City. Photo by José Fernando Rodrigues Bezerra.



Figure 6 Gullied area in São Luis Municipality, Maranhão State, during rehabilitation work .Photo by Jose Fernando Rodrigues Bezerra.

The fourth area is the Paraíba do Sul middle drainage basin, in Rio de Janeiro State, mainly on Oxisols, Alfisols, Entisols and Inceptisols, all of them with sandy loam textures. Vegetation clearance since the mid-18th century was critical in initiating erosion. Vegetation was cleared for coffee plantations and was followed by extensive cattle ranching, which caused land degradation and fertility loss on these soils (Guerra & Botelho, 2012). The concentrated erosive summer rainfall regime accelerated erosion.

The fifth region is *Campanha Gaúcha* in Rio Grande do Sul State, including the municipalities Alegrete, São Francisco de Assis, Santana do Livramento, Itaqui and Manuel Viana. The soils are erodible sandy or sandy loam Alfisols or Oxisols and experience an erosive rainfall regime. Soya-bean plantations and cattle ranching, both without conservation measures, are the main factors explaining land degradation. Wind erosion is also a local problem.

The sixth area is *Triângulo Mineiro*, in western Minas Gerais State. This includes the municipalities Uberlândia, Uberaba and Araguari. The main soil types are erodible sands and sandy loam Oxisols, Alfisols and Inceptisols. Accelerated erosion processes were initiated by vegetation clearance for cattle ranching. The concentrated erosive rainfall regime is another factor which explains widespread gully erosion in the region.

Figure 3 shows five classes of susceptibility to water erosion, ranging from very low to very high. Most of the very low and low classes are in Amazonia, where slope angles are gentle. Although there has been forest clearance in recent decades,

this is remains the most vegetated region in Brazil. The medium class is present in different parts of Brazil and this is due to a combination of factors (soil properties, land use and cover, rainfall regime and slope characteristics). Most of the high and very high classes are concentrated in Southern and South East Brazil, where there is the highest pressure on land use, due to intensive agriculture practises, often without conservation measures.

Some of the soils are very erodible and experience intense erosive summer rainfall (December-March). High and very high soil erosion classes are present in Amazonia, due to forest clearing and intensive soil use, mainly for soya-bean crops often without soil conservation practises.

It is very difficult to accurately estimate total soil erosion for such a large country as Brazil. The Handbook of Sustainable Consumption (Consumo Sustentável, 2005) estimated the overall national loss of soil due to soil erosion to be 822-1000 million tonnes per year.

Given the large size (area 8,547,403 km²) and population (190 million in the 2010 Census) of Brazil, it is difficult to accurately assess the magnitude and costs associated with soil erosion. Best estimates are that the average rate of soil erosion is ~15.4 t ha⁻¹ y⁻¹ (Embrapa, 2002). This compares with a maximum tolerable rate of soil erosion (i.e. a rate which will not seriously impair soil fertility) of ~2 t ha⁻¹ y⁻¹. Similarly, estimates of total costs of damage caused by soil erosion are difficult to assess. This problem is compounded by the diversity of associated costs and difficulties in accurately assessing costs. Expenditure includes costs to replace lost nutrients, costs to repair sediment damage to water resources, damage to rural roads and other infrastructure and associated fuel and electricity costs. National costs are estimated at USD 5 billion per year, while average costs of soil erosion for farmers is estimated at USD 22 per hectare per year (Embrapa, 2002).

3 Soil Conservation

In order to rationalize land use and management in Brazil, drainage basin management projects have been in progress since 1980. The drainage basin can be considered a natural planning unit, where the integrative and dynamic action of land uses can be systematically analysed, and where each component may interact with other parts of the system (Bertoni & Lombardi Neto, 1990).

Paraná State was a pioneer in terms of projects on micro-drainage basin productivity management. This was because of intense land degradation in the State during the 1980s. This was especially problematic in the north-west of Paraná State, due to intensive agricultural activities (Guerra & Botelho, 2012). Some 15 years after this project started, over 2,148 micro-drainage basins are managed by the project, encompassing 365 municipalities and covering 6.2 million hectares, some 45% of the agricultural area of the State. The results can be measured by increased crop production and productivity, and decreased costs, in terms of decreased use of fertilizers, the maintenance of rural roads and water treatment.

In Santa Catarina State, a micro-drainage basin project was implemented from 1991-1997, using funding from the World Bank. The project helped 81,000 farmers, in 520 micro-drainage basins, and benefited 25% of the State's agricultural areas. Other States, including São Paulo, Mato Grosso do Sul and Rio de Janeiro, have already started micro-drainage projects. However, to date, their actions have targeted very few micro-drainage basins (Guerra & Botelho, 2012).

Micro-drainage basin project strategies can be summarized in three main basic characteristics: 1. to increase soil vegetation cover duration and extent; 2. to improve soil structure and drainage, and 3. to control soil surface flow, (Bragagnolo, 1994). The increase in vegetation cover protects soil against splash erosion, induces better soil structure due to increased SOM content, reduces runoff and increases infiltration.

Examples of effective soil conservation practises in Brazil include:

- 1 Increased extent and density of vegetal cover.
- 2 Use of green manure (i.e. the addition and incorporation of non-decomposed vegetal biomass on fallow soils).
- 3 Good soil management practises, particularly minimum tillage.
- 4 Maintaining cover on soils, especially retaining harvest residues on topsoils, thus adding organic matter to soil systems.
- 5 Improved cattle management systems and optimizing the combination of these systems with arable cropping systems to minimize soil erosion.

6 Re-afforestation and particular protection of riparian vegetation and erodible soils.

7 Contour cultivation. Experiments in Brazil have shown this can reduce runoff by $\leq 30\%$ and soil loss by $\leq 50\%$ (Bertoni & Lombardi Neto, 1990).

8 Vegetative buffers (strips of vegetation) in agricultural areas. These act as physical barriers to runoff and erosion and encourage the infiltration of water.

9 Strips of stones, where stones in agricultural areas are placed in small channels dug parallel to contour lines to reduce water surface flow.

10 Construction of small retention basins in small depressions, between areas of permanent agriculture.

11 Construction and maintenance of vegetation barriers to act as 'windbreaks' and thus decrease wind erosivity in areas subject to wind erosion.

All these conservation practises have promoted much more sustainable agriculture in Brazil, which improves soil drainage and simultaneously reduces soil erosion. Nevertheless, in many areas, soil degradation still occurs, due to the use of conventional agricultural systems and cattle ranching.

Experimental stations and modelling play important roles in assessing soil loss and runoff in Brazil. For instance, SWAT (Soil and Water Assessment Tool) has been used to develop conservation practises to reduce runoff, soil loss and nutrient losses in São Bartolomeu drainage basin, Viçosa Municipality, in Minas Gerais State (Rocha *et al.*, 2012). The model allowed the identification of critical areas in terms of runoff generation, sediment yield and nutrient loss. Conservation practises were simulated to reduce the impact of these processes. The simulated results showed a mean annual runoff (R) of 35 mm, mean annual sediment yield (SY) of 51 t ha⁻¹ y⁻¹, 3.6 t ha⁻¹ y⁻¹ loss of total nitrogen (TN) and 1.6 t ha⁻¹ year⁻¹ loss of total phosphorus (TP). After taking into account conservation practices, the results showed an increase in water infiltration, reducing R, SY, TN and TP by 18, 66, 25 and 30%, respectively (Rocha *et al.*, 2012).

The advance in techniques which apply geoprocessing and Geographical Information Systems (GIS), together with erosion monitoring and modelling, have increased our knowledge on

soil erosion and soil conservation. These techniques encompass mapping soil types and soil potential use and other types of maps, field and laboratory work, the adoption of rational soil use and soil management strategies and micro-drainage basin management. These techniques are of considerable applied value, both to farmers, who deal directly with soils, and to State governments, who invest in soil conservation. The Federal Government also invests in soil conservation through several national agencies, especially Embrapa.

4 Conclusions

Soil erosion is the product of complex interactions between rainfall regime, soil properties, slope characteristics, vegetation cover and land use and management. Their interaction often produces excessive erosion rates in Brazil. Understanding soil erosion as a geomorphological process is an essential step towards developing effective soil conservation strategies. There is a close association between soil classes in Brazil and soil erodibility and field measurements suggest erosion rates often far exceed tolerable levels and thus impair the ability of soil systems to sustainably produce crops.

Quantitative data on measured soil erosion rates are sparse in Brazil. However, the few available studies show total soil loss often exceeds $50 \text{ t ha}^{-1} \text{ y}^{-1}$ and can exceed $100 \text{ t ha}^{-1} \text{ y}^{-1}$. Thus, Brazil is one of the global erosion 'hotspots.' Due to the very diverse environmental conditions, land use and management, it is very difficult to produce reliable average estimates of soil loss for the whole country. It is suggested a useful step would be to produce soil erosion estimates for the five regions of Brazil. This will require an integrated programme of surveys, monitoring and modelling to be conducted by Universities and Research Centres throughout Brazil. Such data would inform the viability of soil conservation practises. Integrated management of drainage basins offers a promising way forward for effective soil conservation in Brazil.

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