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Farming expansion and land degradation in Western Bahia, Brazil

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BATISTELLA, M. & VALLADARES, G.S. **Farming expansion and land degradation in Western Bahia, Brazil**. Biota Neotrop. 9(3): http://www.biotaneotropica.org.br/v9n3/en/abstract?article+bn00909032009.

Abstract: Land degradation by soil erosion has called attention in tropical developing countries, particularly when natural vegetation is converted to farmland. Thus, the occupation of Brazilian savannas in Western Bahia is a matter of growing environmental concern. There are approximately 10 million hectares affected by this relatively recent land-use dynamics, but little is known about the temporal and spatial distribution of the process. To better understand such transformations, this paper addresses three related topics: land use/land cover (LULC) in 1985 and 2000; LULC dynamics between 1985 and 2000; and risk of land degradation by soil erosion as a function of farming expansion. The study area is located in Northeastern Brazil, between the coordinates 11° S and 46° 30' W and 14° S and 43° 30' W. All classes of natural vegetation cover decreased their areas during the period of study. Savanna (*cerrado*) lost 21.0% of its original area. Modern farming and irrigated areas increased 154.4 and 526.0%, respectively. Farming expansion reached 1,675,233 ha. Moderate risk of land degradation by soil erosion increased from 28.0 to 36.8% of the landscape mosaic between 1985 and 2000. The spatial and temporal dynamics observed reproduces development and land degradation examples of other savanna lands in Brazil. The integrity of native vegetation cover and the dissemination of soil and water conservation practices should be considered. This research contributes with an understanding of landscape transformations as a baseline for strategic environmental and land-use planning within the region.

Keywords: *landscape change, land-use/land-cover, soil erosion, Brazilian savannas, Bahia.*

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Resumo: A degradação da terra por erosão do solo tem chamado atenção em países em desenvolvimento, particularmente quando a vegetação nativa é convertida em área agrícola. Portanto, a ocupação do cerrado no Oeste da Bahia é um tema de crescente preocupação ambiental. Existem aproximadamente 10 milhões de hectares afetados por esta recente dinâmica de uso da terra, mas pouco se sabe sobre a distribuição temporal e espacial do processo. Para melhor entender estas transformações, este trabalho aborda três tópicos relacionados: uso e cobertura da terra em 1985 e 2000; dinâmica do uso e cobertura entre 1985 e 2000; e risco de degradação da terra por erosão de solo como função da expansão de áreas agrícolas. A área de estudo localiza-se no Nordeste brasileiro, entre as coordenadas 11° S e 46° 30' O e 14° S e 43° 30' O. Todas as classes de vegetação nativa diminuíram suas áreas durante o período de estudo. O cerrado perdeu 21,0% de sua área original. A agricultura moderna e as áreas irrigadas aumentaram 154,4 e 526,0%, respectivamente. A expansão de áreas agrícolas alcançou 1.675.233 ha. O risco moderado de degradação da terra por erosão de solo aumentou de 28,0 para 36,8% do mosaico de paisagem entre 1985 e 2000. A dinâmica espacial e temporal observada reproduz exemplos de desenvolvimento e degradação da terra de outras áreas de cerrado no Brasil. A integridade da cobertura vegetal nativa e a disseminação de práticas de conservação de solo e água deveriam ser consideradas. Esta pesquisa contribui para um entendimento das transformações da paisagem como uma base para o planejamento ambiental estratégico e do uso das terras na região.

Palavras-chave: *mudanças na paisagem, uso e cobertura da terra, erosão do solo, cerrado, Bahia.*

Introduction

Land degradation by soil erosion has called attention in tropical developing countries, particularly when natural vegetation is converted to farmland. Vegetation cover protects the soil from the impacts of rain drops, smoothing erosive processes (Favis-Mortlock & Guerra 1999). Rain drops can also produce crusts on soil surfaces, which reduce the infiltration potential (Roth 1997). Infiltration is the movement of water through the soil by capillarity and gravity forces (Bertoni & Lombardi Neto 1985). Thus, soil structural and textural characteristics also define the potential of water infiltration and erosion. Depending on management practices, land use may cause compactation and decrease soil moisture (Neufeldt et al. 1999). Besides rainfall and vegetation cover, topography plays an important role in defining erosion potentials. The size and amount of particulated materials in water runoffs are closely related to slope variations (Wischmeier & Smith 1978, Renard et al. 1997, Lu et al. 2004).

The occupation of Brazilian savannas is a matter of growing environmental concern, due to land-use intensification during the past decades (Brannstrom 2001, Neufeldt et al. 2002). The expansion of soy bean fields, for instance, can cause the erosion of approximately 8 mg.ha^{-1} per year if conservative practices are not adopted (Mattsson et al. 2000). Erosion control in agricultural systems is necessary to avoid land degradation and nutrient loss (Giller et al. 1997). It is estimated that an average of 20 to 70 kg.ha^{-1} of Nitrogen and Potassium are exported from agricultural lands in Latin America annually (Boddey et al. 1997). When comparing natural savanna areas with pasturelands in Brazil, Balbino et al. (2002) showed that, at various soil depths, the pore volume was smaller in pastures than in areas with natural vegetation cover, characteristic that may increase land degradation.

The Western Region of Bahia State, located in the transition between savanna (*cerrado*) and dry forest (*caatinga*) biomes in Brazil, was traditionally used for extensive cattle ranching and traditional farming, but observed an important development of the agricultural activity beginning in the early 1980's (Nepstad et al. 1997). Farmers have invested in the production of grains (mainly soy bean and corn), and irrigated perennial crops, including coffee (AIBA 2001). Most of these farmers are originally from Southern Brazil (e.g., Rio Grande do Sul, Santa Catarina, and Paraná States), but also from other states and even from foreign countries (e.g., Portugal and United States).

This fast and intense change in land use has caused environmental impacts, such as habitat loss, alteration of animal populations, biodiversity reduction, outflow reduction of rivers draining the region, hydric, eolian, and genetic erosion (Baccaro 1999). There are approximately 100,000 km^2 affected by this relatively recent land-use dynamics, but little is known about the temporal and spatial distribution of the process. The impacts vary among the distinct watersheds within the region, as a function of land conversion and geomorphic characteristics. Moreover, with the current pace of development, investments in the region tend to grow, stimulated by the recent success of the Brazilian agribusiness.

The outcomes are also noticed in urban and peri-urban areas where land development has promoted the sprawl of impermeable areas and even the establishment of new towns, such as Luís Eduardo Magalhães (Chiara 2002). Thus, in order to support a more sustainable development within the region, land-use/land-cover (LULC) dynamics and the risk of land degradation by soil erosion need to be spatially understood. To accomplish such task, this paper addresses three related topics: LULC in 1985 and 2000; LULC dynamics between 1985 and 2000; and risk of land degradation by soil erosion

Material and Methods

1. Study area

The study area is located in the Western portion of Bahia State, Northeastern Brazil, between the coordinates 11° S and 46° 30' W and 14° S and 43° 30' W, including three watersheds (Grande, Corrente, and Carinhanha), all tributaries of the São Francisco River (Batistella et al. 2003).

This region has two well-defined seasons: the dry season with mild temperatures between May and September, and the hot and rainy season between October and April. Its geographic location assures high temperatures during most of the year, due to the powerful solar radiation. The average maximum and minimum precipitations vary in the eastern-western directions from 800 mm to 1,600 mm/year. The annual average for relative humidity is about 70%, ranging between 50% in August and 80% in December (Prefeitura Municipal de Barreiras 2000).

The geological features within the study area includes Formations of the: Holocene, composed by recent sediments; Quaternary (i.e., Vazantes Formation), with sediments from various origins, sometimes concretionary; Superior Cretaceous (i.e., Urucuia or Itapecuru Formation), which encompasses the largest part of Western Bahia and is constituted by sandstone; and Superior Cambrian (i.e., Bambuí Group), where limestones or clastic materials can be found (Jacomine et al. 1976).

Based on structural characteristics and topographic variation, Jacomine et al. (1976) distinguished the following geomorphological units in Western Bahia: Alluvial Plains, between 350 and 400 m high, with undulating terrain; Western Plateau, occupying approximately half of the entire study area, with altitudes up to 900 m; Oriental Plain, a large flat surface, inserted between the principal front of the Western Plateau and the São Francisco River, with altimetric variation ranging between 400 and 600 m; Northern Plains and Pediplanes, a narrow area including an irregular intermountain plain with pediplaned sections, located between the mountains delimiting the Oriental Plain and the boundaries of the study area; and Mountains and Inselbergs, represented by solid elevated residuals.

Oxisols predominate in the Western Plateau. In the river valleys and wetlands with palm trees, Aquox and Histosols are more frequent. These soils have low natural fertility, with the flat topography being the main advantage for agricultural use. In the plains, soil types include Oxisols, Ultisols, Psamments, and, less frequently, Alfisols. The considerable soil variation in the region is closely related to the variation in the original geologic substract. In mountains and inselbergs, shallow Entisols predominate (Valladares 2002).

Vegetation formations within the Western Region of Bahia follow latitudinal, longitudinal, and altimetric gradients and are associated with physical factors such as climate, soils, and topography. In the Western Plateau, the savanna (*cerrado*) is the dominant physiognomy, usually correlated to flat surfaces, Oxisols, and Psamments. The more representative patches of seasonal forest cover the central portion of the study area, where calcareous rocks dominate. Most of the São Francisco River valley and the northeastern portion of the study area belong to an ecological transition between the savanna (*cerrado*) and the dry forest (*caatinga*). Riparian vegetation is associated with natural landscape corridors, such as the main rivers and smaller streams (Batistella et al. 2003).

2. Data gathering

Bibliographic, cartographic, and satellite imagery searches, together with data acquisition during fieldwork was the first step to build

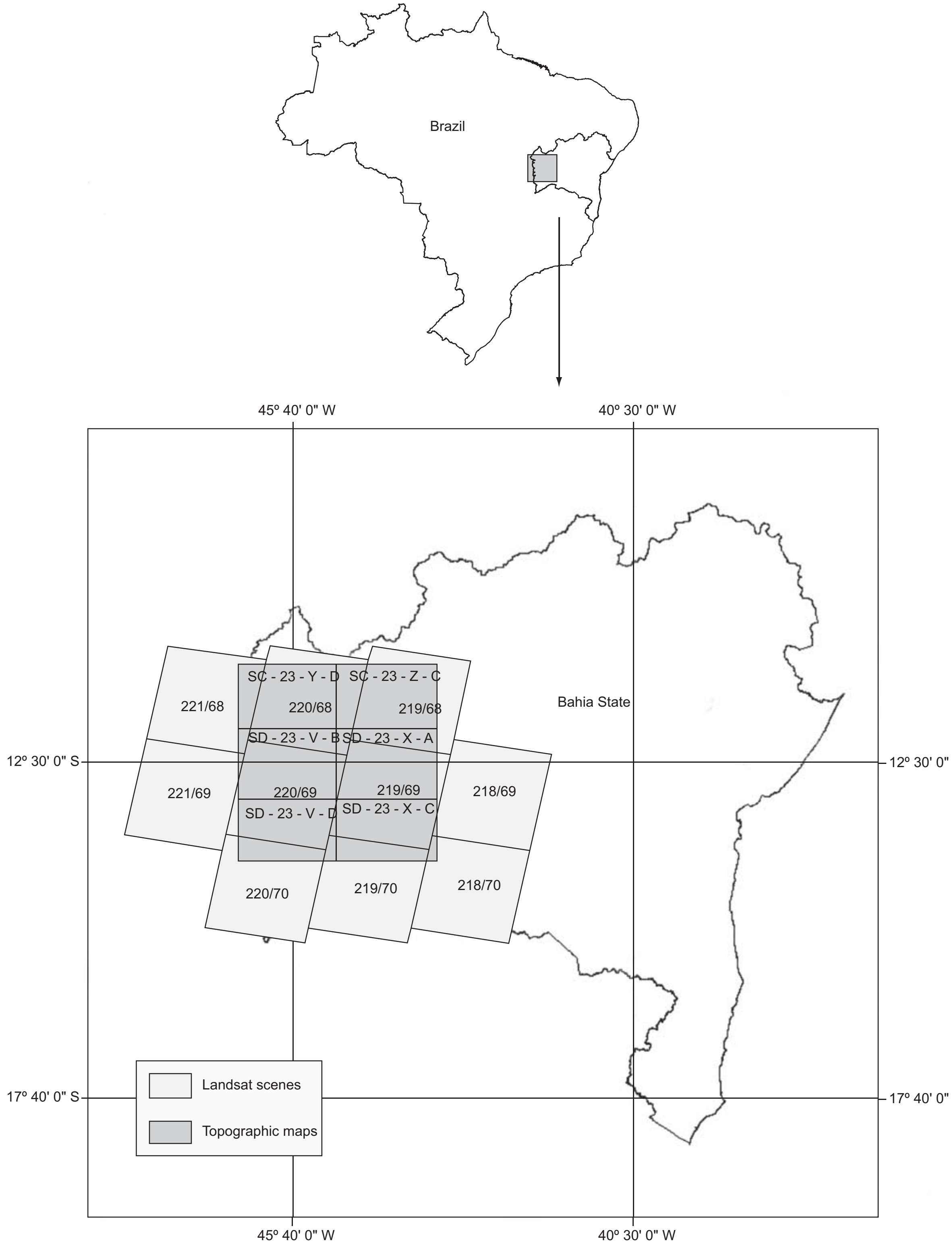


Figure 1. Topographic maps and Landsat scenes covering the study area in Western Bahia, Brazil.

maps in 1:250,000 scale (IBGE 1984a-f) and Landsat TM and ETM$^+$ scenes covering the study area.

After preliminary tests, dry season satellite imagery was selected to maximize spectral differentiation between LULC classes. Landsat TM and ETM$^+$ scenes were acquired for 1985 and 2000 (Table 1). Using image processing systems, these scenes were georeferenced. The elaboration of mosaics encompassed the area covered by the six topographic maps.

3. Mapping land-use and land-cover dynamics

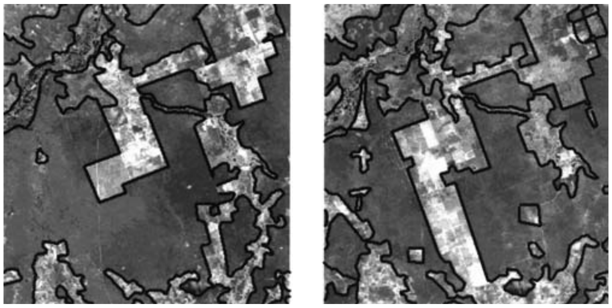
LULC maps were produced for 1985 and 2000 through the use of LANDSAT TM 5 and ETM$^+$ 7 images with spatial resolution resampled to 30 m. Visual interpretation of the boundaries between LULC classes was performed 'on the fly' at scales ranging from 1:150,000 to 1:180,000. The cartographic output was represented in 1:250,000 based on the available topographic maps for the region. The minimum map unit was of approximately 13 ha (i.e., polygons of 0.04 cm^2). As the geometric correction was performed for a maximum error of 30 m (i.e., 1 pixel), the vectors generated for year 2000 were overlayed to the 1985 mosaic for the edition of LULC polygons in 1985 (Figure 2).

LULC maps for Western Bahia used a legend based and adapted from Brasil (1982), Veloso et al. (1991), Eiten (1994), Ribeiro & Walter (1998), Walter & Sampaio (1998), Araújo & Martins (1999), and Araújo et al. (1999). A summarized description of each LULC class is listed below.

Table 1. Landsat scenes used and date of acquisition in 1985 and 2000.

Tabela 1. Cenas Landsat utilizadas e datas de aquisição em 1985 e 2000.

Scenes	Dates of Acquisition	
	1985 (LANDSAT TM)	2000 (LANDSAT ETM$^+$)
221/68	02.09.85	22.11.00
221/69	10.08.85	05.08.01
220/68	10.08.85	27.08.00
220/69	10.08.85	27.08.00
220/70	26.08.85	14.10.00
219/68	16.06.85	01.07.99
219/69	20.09.85	20.08.00
219/70	03.08.85	17.06.00
218/69	20.08.85	22.03.00
218/70	03.08.85	28.03.99



1985 2000

Figure 2. Land-use/land-cover vectors overlaid to subsets of Landsat mosaics from 1985 and 2000.

Figura 2. Limites interpretados para o uso e cobertura da terra, sobrepostos

Seasonal Forest can be classified as semi-deciduous or deciduous vegetation in function of biophisical factors, such as latitude, climate, topography, soil, and floristic composition. In Western Bahia, it occurs in patches of various sizes, located in higher elevations, over calcareous and pelitic substrate.

Riparian Vegetation is spatially associated with rivers, streams, and wetlands. It includes gallery forests, grassy and herbaceous-shruby formations. The gallery forest defines landscape corridors along the water courses. This broadleaf evergreen vegetation is often encircled by narrow herbaceous-shruby formations as a buffer zone for the abrupt transition to savannas and agricultural lands. Riparian vegetation is characterized by the dominance of *Mauritia flexuosa*, a very typical palm tree (*buriti*). It is found in saturated soils, generally covering flat areas, bordering drainage lines.

Savanna (*Cerrado*) areas contain scattered trees and bushes over a grassy ground cover, without a continuous canopy. It is characterized by the presence of low trees, with irregular and twisted ramifications, generally showing evidences of burning events. Some shrub species present perennial deep roots that allow sprouting after burning or cutting. Generally, the tree stems have coarse barks, and the apical meristems are often piliferous. Leaves are generally rigid and coriaceous. The savanna physiognomy predominates in Western Bahia, being often related to Cretaceous and to patches of Tertiary-Quaternary structures, where Oxisols and Entisols predominate.

Open Savanna (*Campo Cerrado*) of natural or anthropic origin is dominated by herbaceous species, some shrub species, and has no trees. When undisturbed, it is delimited by riparian vegetation. It can also occur in saturated soils, with the presence of surface rocks. In this case, the species composition is different, including plants adapted to this environmental condition. Open savannas are found mainly in the western portion of the study area, by the border with Tocantins State.

Dry Forest/Seasonal Forest/Savanna Transition, locally known as *Carrasco*, *Grameal* or *Catanduva*, is characterized by the abundance of woody climbing species, high density of woody shrubs and trees, lack of stratification, and the absence of *Cactaceae* and *Bromeliaceae*. This vegetation represents a transition between the Brazilian biomes of savannas and dry forests, covering the largest portion of the São Francisco river basin, over Oxisols and Entisols of Tertiary and Quaternary areas.

Dry forest/Seasonal Forest/Savanna/Humid Fields Transition is similar to the vegetation type described above, but with the presence of flooded depressions during the rainy season. It is located mainly in the northeastern portion of the study area.

Traditional Farming is generally undertaken by small farmers with the use of traditional practices. The knowledge of techniques is transmitted through generations and no specific technical orientation is used for land management. The productive system is based on familiar structure. The spatial pattern of traditional farming in Western Bahia is characterized by clusters of small agricultural patches.

Modern Farming is practiced by farmers who use state-of-the-art production techniques (e.g., large scale mechanization and fertilization). The activity is supervised by technical assistance, from the farm to the market. Productivity is generally high and social relations are always based on employment of permanent and temporary workers.

Irrigated Areas encompass areas with infrastructure and procedures for the application of water in agricultural production. Center pivots are often used in Western Bahia, but other sprinkler irrigation systems were also found.

Forestry is the plantation of woody species such as *Pinus* sp. and *Eucaliptus* sp. It occurs in very specific locations within the

Urban Areas include towns and villages occupied mainly by industrial, commercial, and residential complexes.

Water bodies include the main rivers, streams, lakes, and artificial reservoirs.

After the production of preliminary maps based on patterns illustrated in Figure 3, fieldwork was carried out for ground truthing. The cartographic limits and the classification system were checked through aerial and terrestrial surveys. The final products included eleven LULC classes. Using Boolean algebra, the LULC maps for 1985 and 2000 were overlaid in a Geographic Information System following the criteria expressed in Table 2. The legend in this table expresses the classes of land-use and land-cover dynamics in the region as a result of the application of the operator ‘and’ between the LULC classes in 1985 and 2000. Table 2 must be read always from the LULC class in 1985 to the class in 2000. For instance, an area covered by savanna in 1985 that was converted to modern farming in 2000 was reclassified as farming expansion.

4. Accuracy assessment

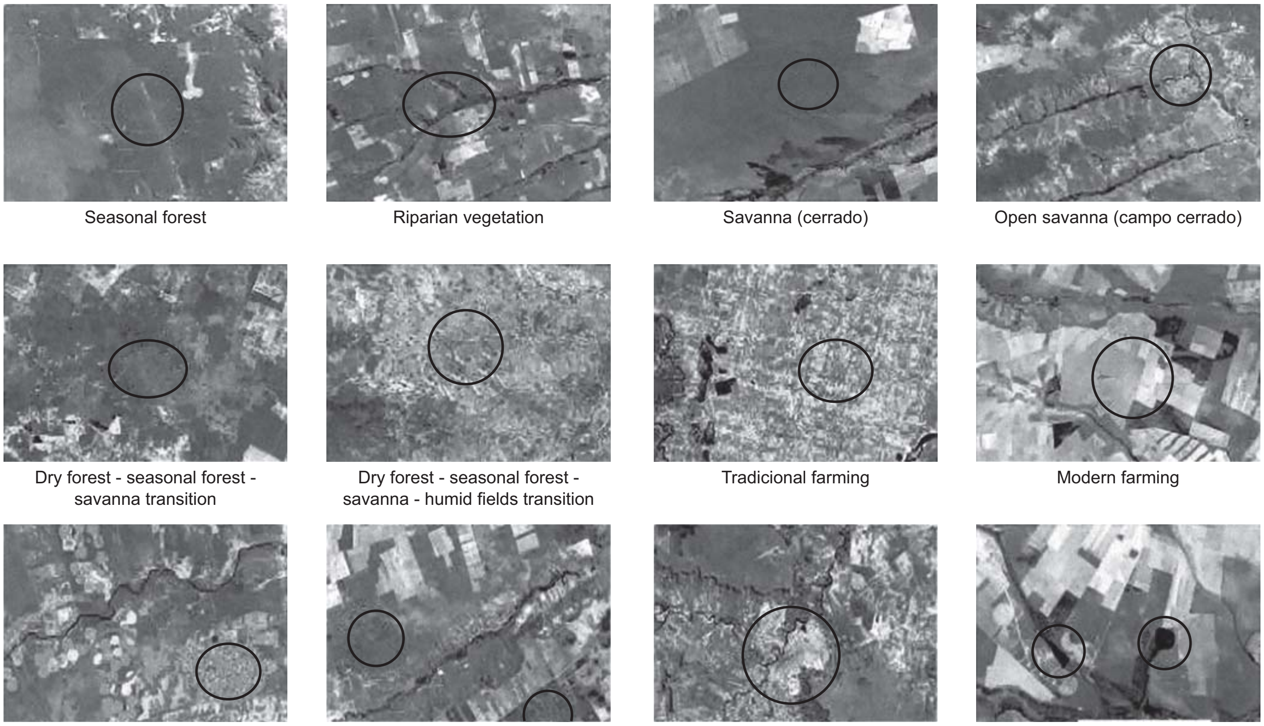
Accuracy assessment is an important part of image classification processes. A common method for accuracy assessment is through the use of an error matrix. Previous literature has provided the interpretations and calculation methods to determine the overall accuracy (OA), producer’s accuracy (PA), user’s accuracy (UA) and Kappa coefficient. The Kappa coefficient is a measure of overall statistical agreement of a matrix, which takes the non-diagonal elements into account. Kappa analysis was recognized as a powerful technique used for analyzing a single error matrix and comparing the difference between different error matrices (Congalton 1991, Smits et al. 1999). Error matrices for the LULC classifications in 2000 and 1985 were produced. The accuracy measures UA, PA and OA are presented. A total of 588 and 869 sample plots were randomly allocated over the 2000 and 1985 LULC classifications, respectively. For the accuracy assessment, these plots were examined through visual interpretation supported by field data and high spatial resolution data (i.e., IKONOS, QUICKBIRD, and aerial photos).

5. Mapping land degradation risks by soil erosion

Land cover protects the soil against erosion. Even in steep areas, this effect is more efficient where vegetation presents greater density and provides more ground cover (Lu et al. 2004). For example, agricultural lands submitted to mechanization suffer greater impact of erosive processes than lands covered by forest plantations. In Western Bahia, peri-urban areas may also play an important role on these processes, as dirty roads and steep slopes created by civil construction speed up material transportation and, as a consequence, increase erosion.

To map land degradation risk by soil erosion, we used a soil map in the scale 1:1,000,000 that includes legends for geology, geomorphology, and slope, and the LULC map for 2000 (Valladares et al. 2002). An additive multi-criteria method, defined by Xavier-da-Silva (2000) as weighted mean, was applied (Equation 1). The integration of GIS and multi-criteria methods can be found in several works (Jankowski 1995, Malczewski 1999, Gomes & Estellita Lins 2002). After the conversion of vector data to raster matrices, we applied the following algorithm:

$$Aij = \sum_{k=1}^{n} (Pk.Nk) \qquad (1)$$



Seasonal forest
Riparian vegetation
Savanna (cerrado)
Open savanna (campo cerrado)
Dry forest - seasonal forest - savanna transition
Dry forest - seasonal forest - savanna - humid fields transition
Tradicional farming
Modern farming
Irrigated areas
Forestry
Urban areas
Water

Figure 3. Land-use/land-cover classes mapped in Western Bahia, Brazil.

able 2. Classification scheme used to map land-use and land-cover dynamics in Western Bahia, Brazil.

abela 2. Esquema de classificação usado para mapear a dinâmica de uso e cobertura da terra na Região Oeste da Bahia, Brasil.

Land-use/Land cover	**2000**											
1985	**Seasonal Forest**	**Riparian vegetation**	**Savanna (*Cerrado*)**	**Open Savanna (*campo Cerrado*)**	**Dry Forest-seasonal Forest-Savanna transition**	**Dry Forest-seasonal Forest-Savanna-humid transition**	**Traditional farming**	**Modern farming**	**Irrigated areas**	**Foresty**	**Urban areas**	**Water**
Seasonal Forest	🟩						■	■	■		▧	
Riparian vegetation		🟩					■	■	■			▨
Savanna (*Cerrado*)			🟩				■	■	■	■	▧	▨
Open Savanna (*campo Cerrado*)				🟩			■	■	■	■	▧	
Dry Forest-seasonal Forest-Savanna transition					🟩		■	■	■		▧	▨
Dry Forest-seasonal Forest-Savanna-humid transition						🟩	■	■	■			▨
Traditional farming	░	░	░	░	░	░	🟩	⫼	▥		▧	▨
Modern farming	░	░	░	░	░	░	☰	🟩	▥	🟩	▧	
Irrigated areas		░	░		░		☰	▤	🟩			
Urban areas											🟩	
Water		░										🟩

■ Farming expansion

🟩 Stable

░ Secundary succession

▥ Intensification towards irrigated areas

▤ Extensification towards modern farming

▨ Expansion of water bodies

⫼ Intensification towards modern farming

☰ Extensification towards tradicional farming

▧ Expansion of urban areas

where: Aij = any raster cell; n = number of map units involved; P = weight attributed to the thematic maps, and scaled between 0 and 1; N = value from 0 to 100, attributed to the cell category.

Equal weights (P) of 0.5 were considered for the two themes (criteria). The values for the erosion risks were attributed to the mapped units, in a range of 0 (minimum) to 100 (maximum). The weights and values were defined by the authors, based on their knowledge about the regional soils and ecology. Such definition was submitted to three other experts for consensus evaluation. Areas with shallow soils (Entisols) and steep topography were considered as with very high risk of erosion, independently of the land use and land cover. Table 3 presents the values attributed to each class (in parenthesis), as well as the reclassification for the risk of erosion (cells), defined by the use of the Boolean algebra operator 'and', which allowed the overlay of soil and LULC data. The resultant maps for 1985 and 2000 included five classes of risk, indicating aptitudes for land use and management. These maps were then overlaid to generate a synthetic map expressing where the risk of land degradation by soil erosion increased and decreased within the study area.

Results

1. Land use and land cover

Figures 4 and 5 illustrate LULC maps produced for Western Bahia (Barreiras sheet), in 1985 and 2000, respectively. LULC results for 1985 and 2000, produced through the use of orbital images, enabled not only the quantification of the mapped categories in each date, but also the identification of landscape change patterns and processes. A Kappa index of 0.8396 and 0.7874 was achieved for the 2000 and 1985 classifications, respectively (Tables 4 and 5). Area calculations and the maps themselves show the quantitative dimension and the spatial distribution of landscape changes throughout the region (Table 6).

In 1985, modern farming occupied 631,175 ha of the study area, reaching 1,605,762 ha in 2000. Irrigated areas increased from 17,554 ha in 1985 to 109,883 ha in 2000. Traditional farming surpassed one million hectares during the same period, going from 8.6 to 11.0% of the study area. Urban areas also increased, from 4,335 ha in 1985 to 9,799 ha in 2000 (i.e., 126.0%). Modern farming and irrigated areas increased 154.4 and 526.0%, respectively. In absolute values, this means an expansion of more than 1 million hectares in intensively cultivated areas in the region. Traditional farming presented smaller relative variation (i.e., 28.3%), but expressive absolute variation (261,898 ha). The area of water bodies increased 15.3%, mainly due to the construction of dams and reservoirs for irrigation.

All classes of natural vegetation cover decreased their areas during the period of study. Savanna (*cerrado*) lost 21.0% (i.e., 881,483 ha) of its original area. The dry forest-seasonal forest-savanna transition lost 15.2% and the seasonal forest, 11.5% of their areas, respectively. The open savanna (*campo cerrado*) and the riparian vegetation also lost 6.7 and 2.6% of their areas, respectively. These results indicate that Western Bahia is facing an important LULC change process as a consequence of farming expansion over natural vegetation cover.

2. Land-use and land-cover dynamics between 1985 and 2000

Overlaying the LULC maps through the associations described in Table 2, the more significant processes of landscape change in Western Bahia were identified. Areas where LULC changes did not occur between 1985 and 2000 were considered stable. Farming expansion occurred where land conversion towards farming activities was observed. The conversion of traditional or modern farming to irrigated areas was represented as intensification towards irrigated

was represented as intensification towards modern farming. On the other hand, agricultural extensification processes as well as expansion of water bodies and urban areas are also mapped. The class named "secondary succession" includes areas dominated by farming activities in 1985, with evidences of land abandonment favoring vegetation regrowth (Figure 6).

Approximately 81% of the total area did not present LULC alterations during the period analyzed. Farming expansion reached 1,675,233 ha or 15.49% of the study area. Intensification towards modern farming or irrigated areas occurred only in 0.29% of the total area. Different stages of secondary succession cover 322,281 ha or 2.98% of the 10,813,413 ha mapped. Areas with alterations in Western Bahia landscapes were of approximately 2 million hectares or 19% of the total area. Simple calculations show that farming expansion represents about 81% of the area where LULC change occurred (Table 7).

3. Risks of land degradation by soil erosion in 1985 and 2000

Table 8 shows how the risk of land degradation by soil erosion increased in Western Bahia, as a result of farming expansion and intensification. A very low risk of land degradation by soil erosion occurs mainly in the eastern and northeastern portions of the study area, in flat sites associated with riparian vegetation and forests. The large amount of biomass of these vegetation classes leads to the reduction of erosive processes. These areas also present low density of the drainage network and high soil permeability. The areas with very low risk of land degradation by soil erosion decreased from 9.84 to 8.41% of the total study area in the period of study.

A low risk of land degradation by soil erosion predominates in Western Bahia (53.75% in 1985 and 45.09% in 2000). It is associated with native vegetation cover and flat or slightly undulating terrain. Savannas, forests, and transitions between these vegetation classes are the dominant land covers in areas with low density of drainage network and high soil permeability. Farming expansion and intensification over these areas will certainly increase erosive processes, making them move towards a higher risk of land degradation, as it happened in approximately 9% of the total area during the period of study.

A moderate risk of land degradation by soil erosion increased from 28.01 to 36.81% t of the study area. In the plateau, it occurs over sandstones and Oxisols with loam texture, fine sand predominance, and with weak structure, indicating their susceptibility to erosion. In the plains, moderate risk of land degradation is associated with farming activities, in areas with slightly undulating terrain over surfaces and sediments susceptible to erosion. Areas with deep, less susceptible grounds to erosion, but in undulating terrain and under farming use were also considered with moderate risk of land degradation. These areas lack detailed studies and land management must favor soil conservation.

A high risk of land degradation by soil erosion increased from 2.54 to 3.81% of the study area. It is related to traditional farming in undulating terrains and irrigated agriculture, mainly through central pivot systems, particularly on sandy soils with weak structure. Mechanization and cattle ranching increase the erosive processes in these areas. Thus, soil conservation techniques are recommended. If these practices are not adopted, land degradation processes can lead to irreversible impacts on the productive systems.

A very high risk of land degradation by soil erosion is mainly associated with areas where Entisols predominate. It occurs mainly in the northeastern portion of Western Bahia, where soils are shallow and with low permeability. These areas encompass 5.76% of the

Table 3. Classes of risk of land degradation by soil erosion in Western Bahia, Brazil, based on soil types and land use and land cover. Weights to each class are presented in parenthesis.

Tabela 3. Classes de risco de degradação da terra por erosão do solo na Região Oeste da Bahia, Brasil, com base nos tipos de solo e uso e cobertura da terra. Pesos para cada classe são apresentados em parênteses.

Soil units[1]	**Land Use/Land Cover**										
	Modern farming (80)	**Traditional farming (70)**	**Open Savanna (50)**	**Savanna (30)**	**Seasonal Forest (10)**	**Dry forest / Seasonal Forest/ Savanna/ Humid fields transition (50)**	**Forestry (40)**	**Irrigated areas (100)**	**Urban areas (70)**	**Dry Forest / Seasonal Forest/ Savanna transition (10)**	**Riparian vegetation (10)**
GXbd1(0)	░	░	░	░	⬜	⬜	⬜	▒	⬜	⬜	⬜
GXbd2(20)	▒	▒	░	░	⬜	⬜	░	▒	▒	⬜	⬜
LAd1(40)	▒	▒	▒	░	░	⬜	⬜	▒	▒	⬜	░
LAd2(30)	▒	▒	░	░	⬜	░	⬜	▒	▒	⬜	⬜
LAd3(40)	▒	▒	⬜	░	⬜	▒	⬜	▒	▒	░	░
LAd4(50)	▒	▒	⬜	░	⬜	▒	⬜	⬜	⬜	░	░
LAd5(60)	▒	▒	⬜	▒	⬜	⬜	⬜	⬜	⬜	░	⬜
LAd6(40)	▒	▒	▒	░	░	⬜	░	▒	▒	░	░
LAd7(50)	▒	▒	▒	░	░	⬜	⬜	▓	▒	░	░
LAd8(50)	▒	▒	▒	░	⬜	⬜	⬜	▓	⬜	░	░
LAd9(40)	▒	▒	▒	░	░	⬜	⬜	▒	⬜	░	░
LVAd1(30)	▒	▒	⬜	░	⬜	⬜	⬜	▒	▒	⬜	⬜
LVd1(20)	⬜	▒	░	░	⬜	⬜	⬜	⬜	⬜	⬜	⬜
LVd2(20)	▒	▒	⬜	⬜	⬜	⬜	⬜	▒	▒	⬜	⬜
LVd3(50)	⬜	▒	▒	░	░	⬜	⬜	⬜	⬜	░	░
LVe1(30)	▒	▒	⬜	░	⬜	⬜	⬜	▒	▒	⬜	⬜
PAe1(50)	▒	▒	▒	░	░	▒	⬜	▓	▒	░	░
PAe2(80)	▓	▓	⬜	⬜	▒	⬜	⬜	⬜	⬜	▒	▒
PVAe1(50)	▒	▒	▒	░	⬜	⬜	⬜	⬜	▒	⬜	░
PVAe2(40)	▒	▒	⬜	⬜	░	⬜	⬜	▒	⬜	░	░
PVAe3(40)	▒	▒	⬜	⬜	⬜	⬜	⬜	▒	▒	░	░
PVAe4(40)	▒	▒	⬜	░	░	⬜	⬜	▒	▒	░	░
PVAe5(40)	▒	▒	▒	░	░	▒	⬜	▒	▒	░	░
PVe1(70)	▓	▒	▒	▒	⬜	⬜	⬜	⬜	▒	░	░
PVe2(70)	⬜	▒	⬜	▒	⬜	⬜	⬜	⬜	⬜	░	░
PVe3(80)	▓	▓	⬜	▒	▒	⬜	⬜	▓	▓	▒	▒
RL1(100[2])	█	█	█	█	█	█	█	█	█	█	█
RQo1(50)	▒	▒	⬜	⬜	⬜	▒	⬜	⬜	⬜	⬜	⬜
RQo2(50)	▒	▒	⬜	⬜	░	▒	⬜	⬜	▒	░	░
RQo3(50)	▒	▒	▒	░	⬜	⬜	⬜	▓	⬜	░	░
RQo4(70)	▓	▒	⬜	▒	░	⬜	⬜	⬜	▒	░	░
RQo5(40)	▒	▒	⬜	⬜	⬜	⬜	⬜	▒	⬜	░	░
RQo6(40)	▒	▒	⬜	░	⬜	▒	⬜	▒	⬜	░	░
RQo7(40)	▒	▒	⬜	░	░	▒	⬜	▒	▒	░	░
RUed1(30)	▒	▒	⬜	⬜	⬜	░	⬜	▒	⬜	⬜	⬜
RUed2(20)	⬜	▒	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜
TCp1(70)	⬜	▒	⬜	▒	⬜	⬜	⬜	▓	⬜	░	░

[1] Source for soil types: Jacomine et al. (1976). [2] Areas with this soil type were considered as with very high risk of land degradation by erosion.

⬜ Very low ░ Low ▒ Moderate ▓ High █ Very High

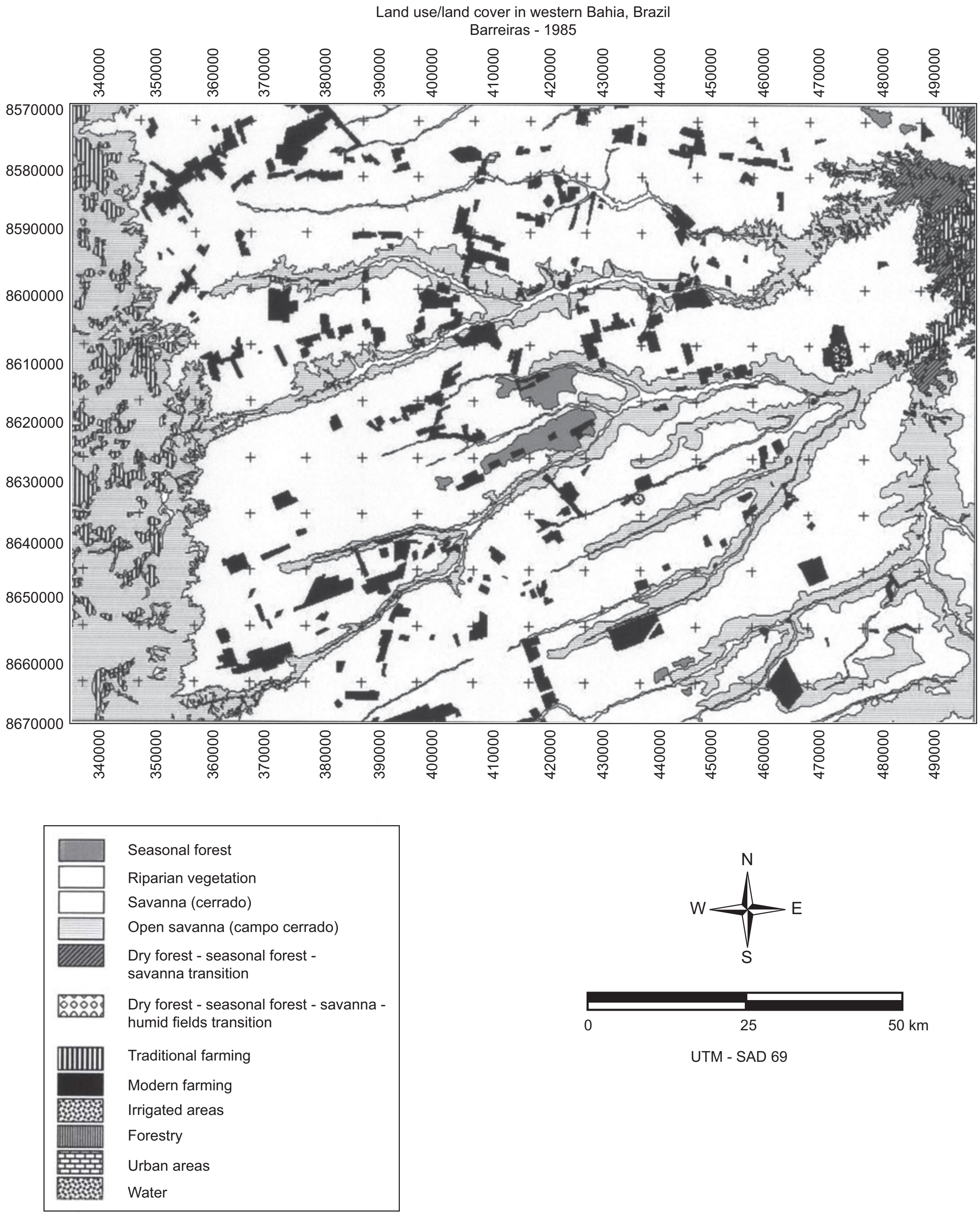


Figure 4. Example of a land-use/land-cover map of Western Bahia, Brazil for 1985 (Barreiras).

Figura 4. Exemplo de mapa de uso e cobertura da terra para a Região Oeste da Bahia, Brasil em 1985 (Barreiras).

predominant. However, because of the very high erosive potential, any anthropic alteration can speed up land degradation processes resultant from landslides.

Although most of the study area remained stable in terms of risks of land degradation by soil erosion, such risks in-

and intensification took place. The process occurred in areas of modern and traditional farming located all over Western Bahia. In the western portion of the area, the risks increased in large patches, where soy bean production predominates. In the eastern portion, the risks increased mainly in scattered small

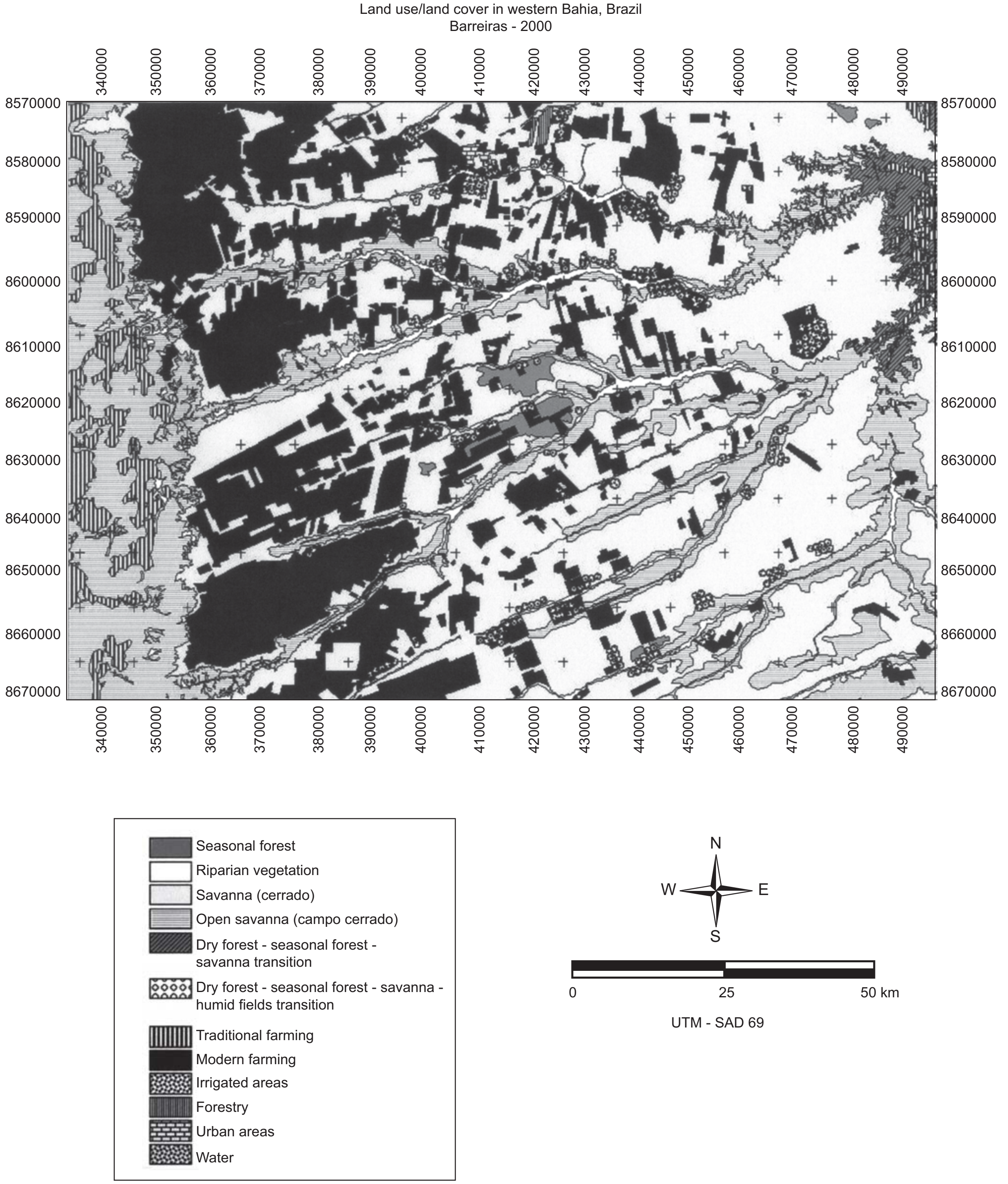


Figure 5. Example of a land-use/land-cover map of Western Bahia, Brazil for 2000 (Barreiras).

Figura 5. Exemplo de mapa de uso e cobertura da terra para a Região Oeste da Bahia, Brasil em 2000 (Barreiras).

Discussion

The recent history of Western Bahia is embedded in the context of the conversion of Brazilian savannas to agricultural lands, particularly by soy bean production (Ribeiro & Walter 1998). Farming expansion

farming is responsible for the increase in soy bean production (IBGE 2005) while irrigated areas produce grains and fruits, including high quality coffee (AIBA 2002). The production of soy bean is responsible for 67% of the cultivated area, 55% of the agricultural production,

Table 4. Accuracy achieved for land-use and land-cover classes in Western Bahia, Brazil (2000).

Tabela 4. Acurácia para as classes de uso e cobertura da terra na Região Oeste da Bahia, Brasil (2000).

Result	**Reference Data**													
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**Total**	**UA%**
1	18	1	3	0	2	0	0	0	0	0	0	0	24	75.0
2	0	22	1	0	0	0	2	0	0	0	0	1	26	84.6
3	5	2	121	14	2	1	0	3	0	0	0	0	148	81.8
4	0	0	6	74	1	0	0	1	0	0	0	3	85	87.1
5	0	2	0	1	61	2	3	1	0	0	0	0	70	87.1
6	0	0	0	0	3	27	0	0	0	0	0	0	30	90.0
7	1	0	1	0	5	0	47	1	0	0	0	0	55	85.5
8	0	0	2	0	4	0	1	66	0	0	0	0	73	90.4
9	0	0	0	0	0	0	0	1	19	0	0	0	20	95.0
10	0	0	2	0	1	0	0	0	0	15	0	0	18	83.3
11	0	0	0	0	0	0	0	0	0	0	20	0	20	100.0
12	0	1	0	0	0	0	2	0	0	0	0	16	19	84.2
Total	24	28	136	89	79	30	55	73	19	15	20	20	588	-
PA%	75.0	78.6	89.0	83.2	77.2	90.0	85.5	90.4	100.0	100.0	100.0	80.0	Kappa = 0.8396	

UA = User's Accuracy; PA = Producer's Accuracy;1 = Seasonal Forest; 2 = Riparian Vegetation; 3 = Savanna (*Cerrado*); 4 = Open Savanna (*Campo Cerrado*); 5 = Dry Forest-Seasonal Forest-Savanna Transition; 6 = Dry Forest-Seasonal Forest-Savanna-Humid Fields Transition; 7 = Traditional Farming; 8 = Modern Farming; 9 = Irrigated Areas; 10 = Forestry; 11 = Urban Areas; 12 = Water.

Table 5. Accuracy achieved for land-use and land-cover classes in Western Bahia, Brazil (1985).

Tabela 5. Acurácia para as classes de uso e cobertura da terra na Região Oeste da Bahia, Brasil (1985).

Result	**Reference data**													
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**Total**	**UA%**
1	31	1	9	1	11	0	0	0	0	0	0	0	53	58.5
2	0	39	6	4	2	5	0	2	1	0	0	0	59	66.1
3	1	1	210	16	2	0	2	4	0	0	0	0	236	89.0
4	0	4	19	87	0	0	1	0	0	0	0	0	111	78.3
5	1	1	14	0	75	5	6	1	0	0	0	0	103	72.8
6	0	0	0	0	0	59	0	0	0	0	0	0	59	100.0
7	0	0	0	0	0	0	51	0	0	0	0	0	51	100.0
8	0	1	0	1	1	0	1	42	0	0	0	0	46	91.3
9	1	4	0	0	6	0	10	0	29	0	0	1	51	56.9
10	0	0	0	0	0	0	0	0	0	0	0	0	0	-
11	0	0	1	0	0	0	0	0	0	0	49	0	50	98.0
12	0	5	3	3	0	1	0	0	0	0	0	38	50	76.0
Total	34	56	262	112	97	70	71	49	30	0	49	39	869	-
PA%	91.2	69.6	80.2	77.7	77.3	84.3	71.8	85.7	96.8	0	100.0	97.4	Kappa = 0.7874	

UA = User's Accuracy; PA = Producer's Accuracy; 1 = Seasonal Forest; 2 = Riparian Vegetation; 3 = Savanna (*Cerrado*); 4 = Open Savanna (*Campo Cerrado*); 5 = Dry Forest-Seasonal Forest-Savanna Transition; 6 = Dry Forest-Seasonal Forest-Savanna-Humid Fields Transition; 7 = Traditional Farming; 8 = Modern Farming; 9 = Irrigated Areas; 10 = Forestry; 11 = Urban Areas; 12 = Water.

(AIBA 2001). To follow these processes, the use of geoinformation and geotechnologies allows relatively rapid assessments, particularly for actions regarding strategic environmental management and land-use planning.

The spatial and temporal dynamics observed in the study area requires effective initiatives for the sustainability of agribusiness and natural resources. The results presented considered a regional scale of analysis, contributing to a broader view on related LULC processes and promoting the identification of opportunities and limitations for conservation and development. They also highlight the need of more detailed maps, particularly for soils and land aptitude to improve the

The rate of native vegetation conversion within the biome *cerrado* is controversial. Machado et al. (2004) estimate an annual loss of 1.1 to 1.5% of the total biome. Ferreira et al. (2007) compared three different studies assessing annual losses from 2001 to 2005. The authors report a variation of *cerrado* conversion from 2.87% in 2001-2002 to 1.20% in 2004-2005. The present study indicates the conversion of 1,360,280 ha of native vegetation between 1985 and 2000, which corresponds to a loss of 0.84% per year. The differences may be due to the various sensors used for land-use and land-cover mapping. While the numbers reported by Ferreira et al. (2007) were based on images with spatial resolution of 1 km (e.g., MODIS and

Table 6. Area, percentage of the study area, and area variation of land-use and land-cover classes in Western Bahia, Brazil.

Tabela 6. Área, porcentagem da área total e variação da área das classes de uso e cobertura da terra na Região Oeste da Bahia, Brasil.

Legend	Area 1985 (ha)	Percentage of the study area 1985 (%)	Area 2000 (ha)	Percentage of the study area 2000 (%)	Absolute variation (ha)	Relative variation (%)
Seasonal forest	577,269	5.3	510,853	4.7	–66,417	–11.5
Riparian vegetation	359,263	3.3	349,771	3.2	–9,492	–2.6
Savanna (Cerrado)	4,197,354	38.8	3,315,870	30.6	–881,483	–21.0
Open Savanna (Campo Cerrado)	1,976,212	18.3	1,844,444	17.0	–131,768	–6.7
Dry Forest-Seasonal Forest-Savanna transition	1,777,386	16.4	1,507,795	13.9	–269,592	–15.2
Dry Forest-Seasonal Forest-Savanna humid fields transition	337,437	3.1	335,909	3.1	–1,528	–0.4
Traditional Farming	924,750	8.6	1,186,648	11.0	261,898	28.3
Modern farming	631,175	5.8	1,605,762	14.9	974,587	154.4
Irrigated areas	17,554	0.2	109,883	1.1	92,329	526.0
Forestry	0	0.0	24,364	0.3	24,364	0.0
Urban areas	4,335	0.1	9,799	0.1	5,464	126.0
Water	10,677	0.1	12,316	0.1	1,639	15.3
Total	10,813,413	100.0	10,813,413	100.0	-	-

Table 7. Area and percentage of the study area for classes of land-use and land-cover dynamics in Western Bahia, Brazil.

Tabela 7. Área e porcentagem da área total das classes de dinâmica de uso e cobertura da terra na Região Oeste da Bahia, Brasil.

Classes	Area (ha)	Percentage of the study area (%)
Stable	8,752,307	80.94
Farming expansion	1,675,233	15.49
Intensification towards irrigated areas	21,138	0.20
Intensification towards modern farming	31,495	0.29
Extensification towards modern farming	421	0.01
Extensification towards traditional farming	3,166	0.03
Expansion of water bodies	1,989	0.02
Expansion of urban areas	5,383	0.05
Secondary succession	322,281	2.98
Total	10,813,413	100.00

allowing the detection of smaller fragments and possibly having as a consequence a larger number for the total native vegetation cover.

Land degradation by soil erosion is an outcome of this *cerrado* conversion. Soil erosion is a physical process driven by socio-economic, cultural, and political causes (Lal 2001). It reduces the integrity of ecosystems and alters land-water interactions. Water quality and soil properties may be affected through the runoff of organic matter and nutrients. On the other hand, irrigation may cause problems of salinization, mainly in the lower portions of the landscape with

This process is intensified by the dryer and warmer climate on these areas when compared to the plateau.

The occidental plateau of Western Bahia has flat topography with altitudes varying from 700 to 900 m (Jacomine et al. 1976) and deep soils (Valladares 2002). Under native vegetation cover, these soils present low erosion potential (Valladares et al. 2002, Embrapa 1999). However, its limestone substrate has high susceptibility to erosion. When subjected to the suppression and degradation of the native vegetation and to intense agricultural activities, erosive processes may take place.

Although the classes of high and very high risk of land degradation by soil erosion added up to only 8.30% of the total study area in 1985 and 9.57% in 2000, this is equivalent to approximately 30% of the entire state of Alagoas. Land classified as with moderate risk of erosion need special attention if converted to agriculture. If soil conservation practices are not adopted, the risk may pass to high or very high.

An alternative to conventional agricultural practices in Brazilian savannas is the no-tillage system, a primary management strategy for increasing soil organic matter (Bayer et al. 2000). The continuous use of no-tillage systems results in the increase of microbial biomass, decrease in soil basal respiration, and increase in soil organic matter content. These practices also improve bulk density and chemical properties of savanna soils (Valpassos et al. 2001). Further studies, in more detailed scales, have to be done to evaluate the impact of these alternative practices within the region.

The abundant water resources, flat topography, and the tropical climate with dry winters and humid summers favor soy bean production, as well as crops such as corn, bean, rice, cotton, and the irrigated fruit plantations. However, farming expansion and intensification caused the conversion and degradation of the native vegetation, mainly the savannas. Factors such as unplanned tourism activities, lack of environmental law enforcement, and migration have contributed to the

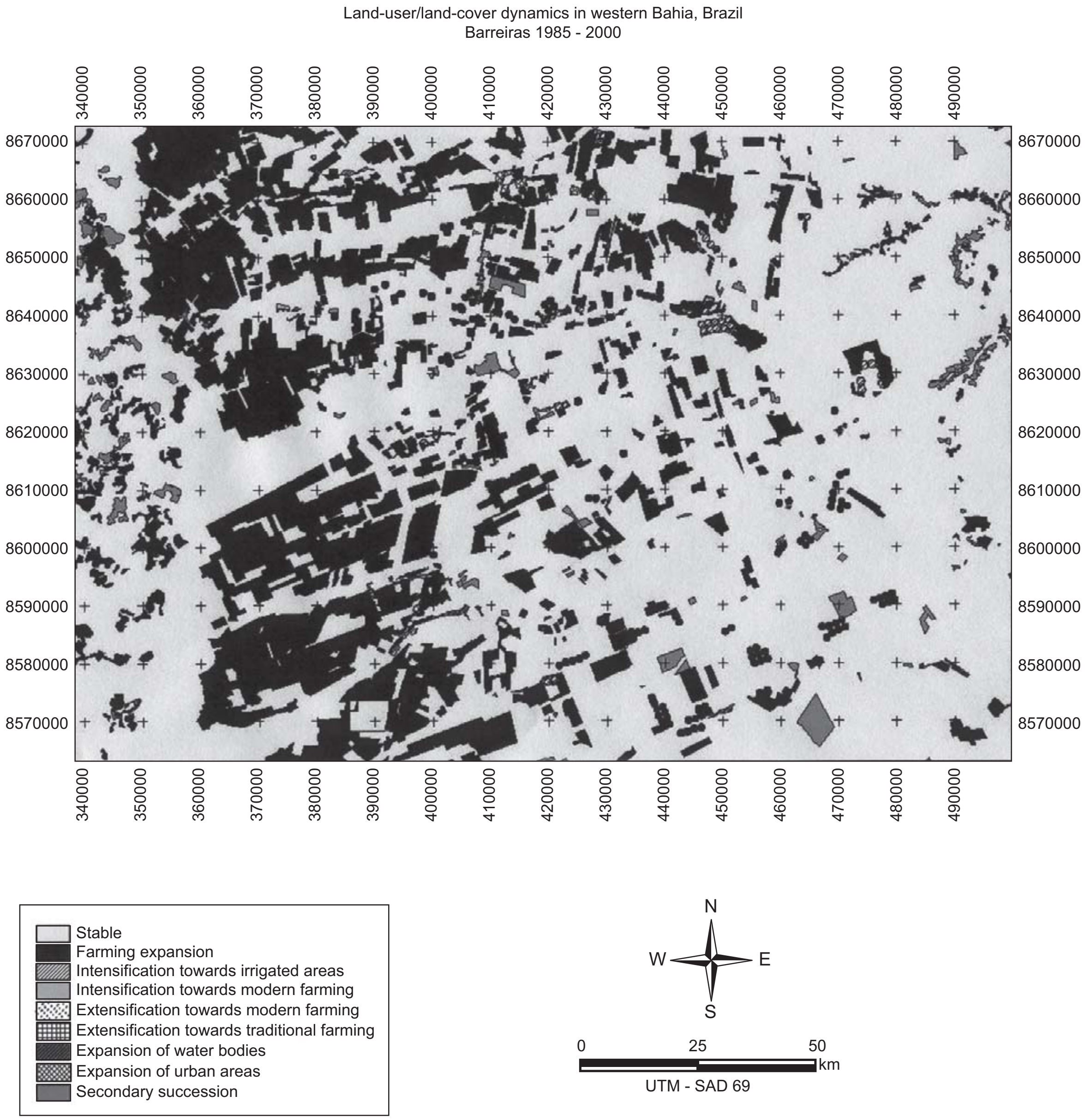


Figure 6. Example of a land-use/land-cover dynamics map of Western Bahia, Brazil (Barreiras).

Figura 6. Exemplo de mapa da dinâmica de uso e cobertura da terra para a Região Oeste da Bahia, Brasil (Barreiras).

Table 8. Area (ha) and percentage of the study area for risk of land degradation by soil erosion in Western Bahia, Brazil in 1985 and 2000.

Tabela 8. Área e porcentagem da área total das classes de risco de degradação da terra por erosão de solo na Região Oeste da Bahia, Brasil em 1985 e 2000.

1985	**2000**													
	Very low		**Low**		**Moderate**		**High**		**Very high**		**Water**		**Total**	
	Area	**%**	**Area**	**%**	**Area**	**%**	**Area**	**%**	**Area**	**%**	**Area**	**%**	**Area**	**%**
Very low	776934	7.90	3055	0.03	181729	1.85	5558	0.06	1	0.00	255	0.00	967532	9.84
Low	332	0.00	4228381	43.00	960854	9.77	94054	0.96	0	0.00	1450	0.01	5285071	53.75
Moderate	50068	0.51	181769	1.85	2454414	24.96	67799	0.69	0	0.00	290	0.00	2754340	28.01
High	111	0.00	19981	0.20	22373	0.23	207640	2.11	0	0.00	0	0.00	250105	2.54
Very high	1	0.00	0	0.00	0	0.00	0	0.00	566092	5.76	0	0.00	566094	5.76
Water	0	0.00	214	0.00	47	0.00	0	0.00	94	0.00	9521	0.10	9876	0.10
Total	827446	8.41	4433401	45.09	3619417	36.81	375051	3.81	566188	5.76	11515	0.12	9833018	100.00

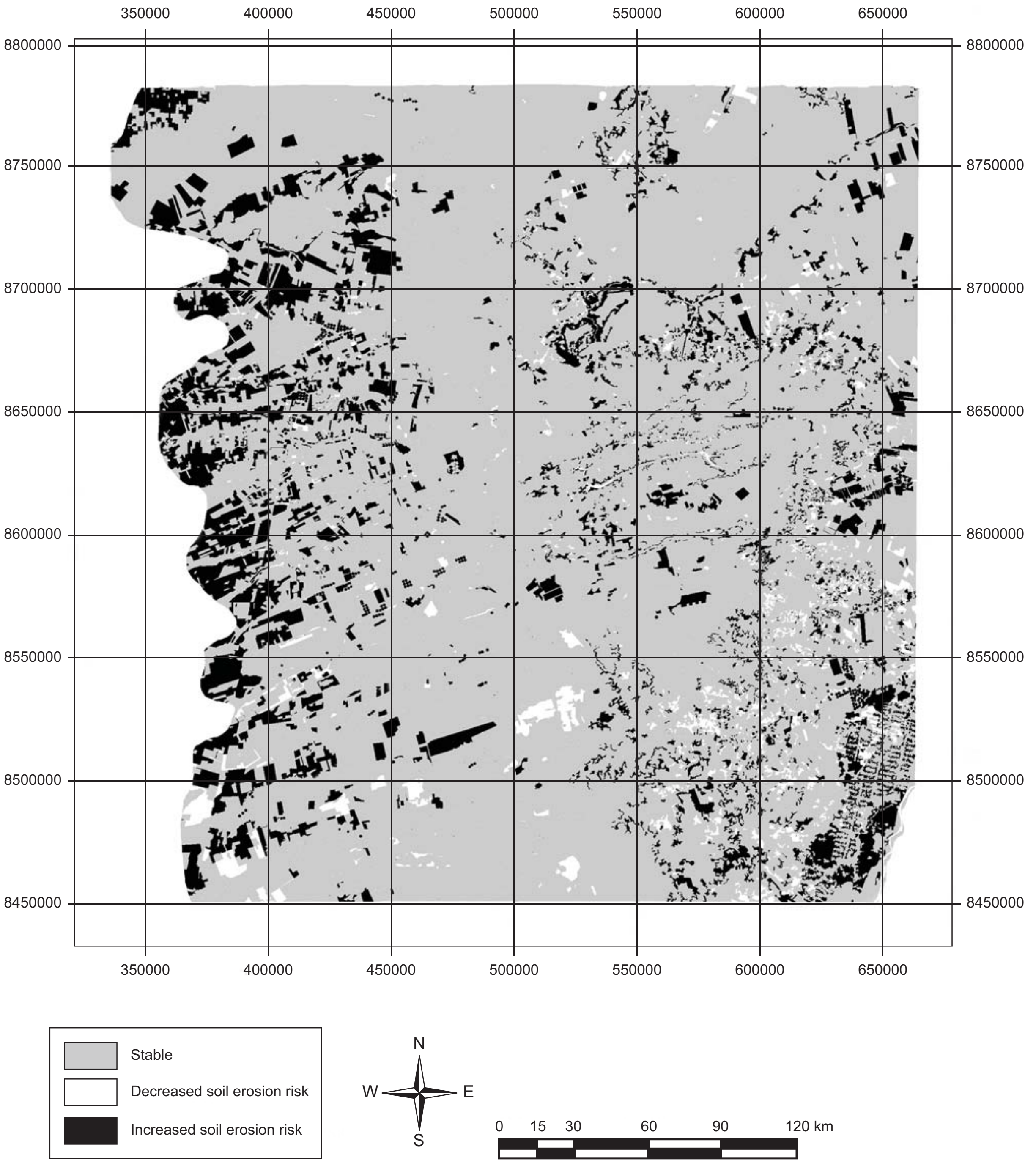


Figure 7. Risk of land degradation by soil erosion in Western Bahia, Brazil between 1985 and 2000.

Figura 7. Risco de degradação da terra por erosão do solo na Região Oeste da Bahia, Brasil entre 1985 e 2000.

should enhance the knowledge about disturbances provoked by these transformations and the driving forces leading to land degradation. Multiscale approaches may also contribute to the understanding of possible environmental impacts caused by farming expansion and

Riparian zones deserve special attention due to their relevant function within the landscapes. The maintenance of these natural corridors may favor the conservation of hydrological cycles and local biodiversity, among other fundamental factors affecting the

Landscape change processes taking place in Western Bahia are mainly due to farming expansion. These processes alter physical and chemical properties of soils, vegetation structure, composition, and stability, as well as biodiversity. Socioeconomic drivers are also part of the process, affecting public policies related to the regional management. Satellite monitoring of these changes and information systems integrating biophysical and socioeconomic data may help future plans to integrate the need of regional development with more sustainable land-use practices.

Although areas covered by natural vegetation still predominate in Western Bahia, the spatial dimension of farming expansion (1,675,233 ha) and farming intensification (52,633 ha) is of great relevance. The process is evident and is fostered by incentives of all sorts, including governmental and private investments. Farming expansion and intensification tend to increase even more, favored by the state-of-the-art agricultural practices in areas of savanna. Counties such as São Desidério, Correntina, Barreiras, Luís Eduardo Magalhães, Formosa do Rio Preto, and Riachão das Neves are the main areas where these processes take place (AIBA 2002).

Farmers in Western Bahia expect a long cycle of highly productive agriculture. However, due to the fragmentation of areas with natural vegetation cover and the consequent loss of biodiversity, land planning measures are urgent to conciliate the regional development with the conservation of natural resources. Recently, the Bahia State government has established land zoning as a priority. Hopefully, the results produced by this research will serve as a basis to mitigate further impacts of farming expansion and intensification, as well as their outcomes in terms of land degradation by soil erosion.

Final Remarks

Farming expansion and intensification in the Western Region of Bahia State reproduce the land degradation and development examples of other savanna lands in Brazil. The positive aspects of such processes include the modernization of production systems and economic development within the region, creating a cycle of development for this portion of the country. Soy bean production and irrigated agriculture play central roles in these transformations.

On the other hand, the challenges of this development approach should include the conservation of native vegetation cover, the advance of agricultural, biotechnological, and ecological research, the creation of a mosaic of conservation units, and the dissemination of soil and water conservation practices.

The engagement of associations of farmers, governmental and non-governmental organizations, public and private institutions at local and regional levels opens new opportunities for a more sustainable development in Western Bahia, avoiding problems such as land degradation by soil erosion. This research contributes with elements related to landscape transformations as a baseline for further initiatives on strategic decision making processes regarding environmental and land-use planning within the region. Land zoning based on detailed socioeconomic and ecological studies may be a reasonable way to overcome the problems associated with farming expansion in the region.

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