Evaluation of the Adequacy of the Land Use in Sub-basin Using GIS and Remote Sensing

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Abstract. The growing negative environmental impacts in rural areas resulting from inappropriate land use and management by farming activities demand an appropriate land use planning, which must take into account the aspects of physical environment, including the land use capacity. This paper aims to evaluate the degree of adequacy of the land use, management and the conservation practices adopted in Ribeirão das Perobas sub-basin, located in Santa Cruz do Rio Pardo, São Paulo State, Brazil, regarding its land use capacity and permanent preservation areas, through GIS and Remote Sensing techniques. The results indicated that the land use and management are below the potential in 11.6% of the study area, appropriated to the potential in 48.16% and above the potential in 32.7% of the sub-basin. The conservation practices are appropriate to the land use capacity in 83.64% of the area and inappropriate in 9.11%. The remaining areas are occupied by native forest, riparian vegetation and ponds. The permanent preservation areas around the streams are occupied by riparian vegetation or ponds in 63.41% of their area and the remaining area are occupied by annual crops, sugarcane and pasture, in disagreement with the Brazilian forest legislation.

Keywords: Land use capacity, Permanent preservation areas, Soil degradation risk

1. Introduction

The conservation planning of land use has the purpose of maximizing the productivity of agricultural areas through a farming system that ensures the maintenance of the productive capacity of the soil and protects it against erosion. Thus, it attempts to ensure adequate utilization of the farmlands considering soil properties, terrain slope and the characteristics of rainfall events in the region. An essential criterion for the rational land use planning is the land use capacity (Pruski 2009).

The land use capacity system, originally developed in the United States, is a technical and interpretative classification that summarizes the characteristics and properties of the land in order to obtain homogeneous classes and define its maximum usability without the risk of soil degradation (Lepsch et al. 1991). The land classification into the land use capacity system enables indication of the adequate farming use and the conservation practices that should be implemented to control soil erosion adequately and ensure high harvests (Lepsch 2011).

The land use capacity classes proposed by Lepsch et al. (1991) range from I to VIII, and the classification system takes into account natural variables, such as soil, relief and climate, reflecting the greater or lesser complexity of conservation practices needed for erosion control. While lands of class I are suitable for all agricultural uses, the lands of class VIII must keep the native vegetation preserved. The land use capacity subclasses, represented by lowercase letters, are qualified according to the nature of restrictions on land use, i.e. erosion risk or presence of erosion (e), soil restrictions (s), excess water (w) or climatic restrictions (c).

Teófilo et al. (2011) evaluated the degree of land use adequacy of the upper course of Rio Pardo, located in Botucatu and Pardinho counties, São Paulo State, to the land use capacity through GIS Idrisi Andes. The map of adequacy showed the areas of land use below, appropriated and above the agricultural use potential, the latter being mainly occupied by annual crops and sugarcane in lands suitable only for pasture and forestry.

The Brazilian Forest Code (Brasil 2012), the law which regulates the protection of native forest in both Permament Preservation Areas and legal reserve areas, defined as Permanent Preservation Areas (PPAs) the marginal bands along any natural river, measured from the regular riverbed to a variable width according to the river width, being 30 meters the minimum PPA for watercourses of less than 10 meters wide; the areas around springs and waterholes in a minimum radius of 50 meters; the hillsides with slopes steeper than 45°; the hilltops and mountaintops with slopes steeper than 25° and a minimum height of 100 meters, and some specific areas. The law also requires farms to maintain at least 20% of their area covered with native forest as legal reserve. The PPA may be computed in legal reserve areas only in cases of non-conversion of native forest areas to other uses, provided that PPA are conserved or in recovery process.

Nardini et al. (2012) mapped the land use conflicts in PPAs along the drainage network in Ribeirão Água Fria watershed, located in Bofete, São Paulo State, through Geoprocessing, and found that although 32.36% of the watershed are covered by native forest, 34.5% of PPAs have conflicting use by pasture (30.4%), forestry (3.6%) and bare soil (0.5%). The replacement of native vegetation in PPA and part of the watershed by human activities caused environmental damage, such as erosion, leaching of soil nutrients and siltation of rivers.

The agricultural land use planning, spatial data acquisition, land use analysis and the numerous methodologies for environmental analysis can be performed with the aid of geotechnology, including Geoprocessing operations and Remote Sensing tools, implemented in Geographic Information Systems (GIS). According to Assad, Hamada and Cavalieri (1998), GIS has numerous advantages, such as minimizing the complexity and the degree of subjectivity of manually estimatives from environmental data crossing; the faster map overlay operation and calculation of areas; getting so many thematic maps as well allow the available variables, and the ease of updating and improving the diagnoses by adding new data in the digital cartographic base. Remote Sensing is essential in spatial data acquisition, mapping and updating maps. Technological advancement enables continuous improvement of spatial, spectral and temporal resolutions of satellite imagery, as well as the planimetric accuracy required by systematic mapping and low cost (Rosa 2005).

In this context, this paper aims to evaluate the degree of adequacy of the land use, management and the conservation practices adopted in Ribeirão das Perobas sub-basin, located in Santa Cruz do Rio Pardo, São Paulo State, Brazil, regarding its land use capacity and permanent preservation areas, through GIS and Remote Sensing techniques.

2. Material and Methods

2.1. Study area

Ribeirão das Perobas Sub-basin is located in Santa Cruz do Rio Pardo county, Midwest of São Paulo State. It is bounded by the following geographical coordinates: latitude 22°47’15.04”S to 22°50’44.29”S and longitude 49°38’55.13”W to 49°43’46.42”W, and its area is 3,061 hectares. The *Figure 1* shows the location of the study area.

Figure 1. Location of the Ribeirão das Perobas Sub-basin.

2.2. Material

The following materials were used to develop this study:

- Topographic chart, sheet Santa Cruz do Rio Pardo, at 1:50,000 scale and 20 meters of equidistance among topographic contours (Instituto Brasileiro de Geografia e Estatística 1973);

- Images from satellites Advanced Land Observing Satellite (ALOS), sensors AVNIR-2 and PRISM, of March 11, 2007; Land Remote Sensing Satellite (Landsat-5), sensor TM, path/row 221/076, of January 29, 2011; Indian

Remote Sensing Satellite (IRS-P6 or Resourcesat-1), sensor LISS III, path/row 328/094, of December 7, 2010 and January 24, 2011;

- Multispectral aerial photographs taken in February 2005, at 1:30,000 scale;

- Detailed soil map of Ribeirão das Perobas Sub-basin, made by Demarchi (2012);

- Geographic Information Systems Idrisi 17.0 version Selva (Eastman 2012) and ArcGIS/ArcMap version 9.3.1 (Environmental Systems Research Institute 2009).

2.3. Methodology

The methodological procedures used in this study are described below:

The detailed soil survey and mapping were made by Demarchi (2012) through photopedology technique (correlation among landscape, air photos and soils), physical and chemical attributes of soil samples collected in the field and morphological description of soil profiles, with minimum mappable area of 2 hectares, according to Brazilian System of Soil Classification (Empresa Brasileira de Pesquisa Agropecuária 2006). The final map was vectorized in GIS ArcMap on the fusion between sensors PRISM and AVNIR-2 of ALOS satellite image, with 2.5 meters of spatial resolution.

The cartographic base was extracted from IGBE topographic chart, and the drainage network was updated from vectorization on ALOS satellite image, fusion PRISM/AVNIR-2. The Digital Elevation Model (DEM) of terrain was interpolated from topographic contours, elevation points and drainage network through the tool “Topo to raster“ of GIS ArcMap, which allows the generation of hydrologically correct DEMs. The slope map was interpolated by the tool “Slope“ in GIS Idrisi Selva, from DEM. The resulting slopes were reclassified into six classes recommended by Soil Survey Staff (1975), as follows: 0–3%, 3–6%, 6–12%, 12–20%, 20–40% and >40%.

The land use capacity map was made in GIS Idrisi Selva according to the classification system proposed by Lepsch et al. (1991). It was used the tool “Crosstab“ to perform a cross-tabulation between soil and slope classes maps, which separated areas of same soil type and slope class into different classes. The resulting classes were analyzed according to the limiting factors on agricultural land use and reclassified into land use capacity classes and subclasses in accordance with the criteria established by Lepsch et al. (1991), França (1963), Zimback and Rodrigues (1993) and Ribeiro and Campos (1999). The limiting factors on land use are: soil fertility, quantified from its chemical attributes; soil depth; permeability and drainage; contribution to runoff; stoniness; flood risk and presence of sheet erosion, rill erosion and gullies.

The land use, management and conservation practices mapping was made through visual analysis and vectorization of thematic classes on ALOS satellite image of March 11, 2007, fusion PRISM/AVNIR-2, in GIS ArcMap. The land use, management and conservation practices were updated for January 2011, the month of greatest rainfall and rainfall erosivity in the region, through visual analysis of color compositions 743, 543, 453 and 321 of Landsat imagery and color compositions 543 and 453 of IRS-P6 imagery described in the *Section 2.2*, in GIS Idrisi Selva.

The classes and subclasses of land use capacity were separated into boolean classes of value 1, so they were associated with maps of land use/management and conservation practices of January 2011 in order to analyze the degree of adequacy of the land use/management and conservation practices to the land use capacity. The resulting thematic classes were reclassified into different degrees of adequacy as shown in *Tables 1* and *2*, elaborated in accordance with the degree of limitation of land use capacity classes and subclasses proposed by Lepsch et al. (1991). These operations were performed in GIS Idrisi Selva.

Land use and management	II e,s	III e	III e,s	III s	IV e	IV e,s	IV s	V w	VI e	VI e,s	VI s	VII e
Native forest and riparian vegetation	4	4	4	4	4	4	4	4	4	4	4	4
Pasture (degraded)	3	3	-	-	3	-	-	-	3	-	3	-
Pasture (without management)	1	2	2	2	2	2	2	2	3	3	2	3
Pasture (managed)	1	1	1	1	2	2	2	2	2	2	2	2
Sugarcane (straw incorporated)	2	2	2	2	2	2	2	3	3	3	3	3
Sugarcane (without management)	2	2	-	-	2	-	-	-	-	-	3	-
Soybean (no-tillage)	2	2	2	2	3	3	3	3	3	-	3	3
Corn (no-tillage)	2	2	2	2	3	3	3	3	3	3	3	3
Cassava (conventional tillage)	-	-	-	-	-	-	-	-	-	-	3	-
Bare soil	3	3	3	3	3	3	3	3	3	3	3	-
Banana	-	-	-	-	-	-	-	-	-	-	2	-
Eucalyptus (cut every 7 years)	1	1	-	-	1	-	2	2	2	2	2	3
Fruit production	1	1	1	1	2	-	-	3	3	-	2	-
Pond	5	5	-	-	5	5	5	5	5	5	5	-
Greenhouse	2	2	-	-	3	-	-	-	-	-	-	-
Highway	2	2	-	-	2	-	-	-	3	3	2	-
Coffee (vegetation among lines)	-	2	-	-	2	-	-	-	-	-	-	-

1. Land use below the potential; 2. Land use appropriated to the potential; 3. Land use above the potential; 4. Native forest and riparian vegetation; 5. Ponds.

Table 1. Degree of adequacy of land use classes to the land use capacity classes.

Conservation practice	IIe,s	IIIe	IIIe,s	IIIs	IVe	IVe,s	IVs	Va	VIe	VIe,s	VIs	VIIe
Pond	4	4	-	-	4	4	4	4	4	4	4	-
Native forest and riparian vegetation	3	3	3	3	3	3	3	3	3	3	3	3
Contour tillage	1	2	2	1	2	2	2	1	2	2	1	2
Downhill cultivation	2	2	-	-	2	2	2	2	2	2	2	-
Highway	1	1	-	-	1	-	-	-	2	2	1	-
Terracing + contour tillage	1	1	1	1	1	1	1	1	1	1	1	1

1. Appropriate conservation practice; 2. Inappropriate conservation practice; 3. Native forest and riparian vegetation; 4. Ponds.

Table 2. Suitability of conservation practices to the land use capacity in Ribeirão das Perobas Sub-basin.

The total area of land use capacity classes was calculated in GIS Idrisi Selva. The adequacy maps of all land use capacity classes were summed, resulting the map of adequacy of the whole sub-basin.

In order to map the land use in Permanent Preservation Areas and the conflicting land uses, these areas were delimited through a pre-defined distance from drainage network and springs, calculated by the tool “buffer“ of GIS Idrisi Selva. The width of PPAs regulated by the Brazilian Forest Code (Brasil 2012) to rivers whose width is less than 10 meters, used in this study, is 30 meters on each riverside and 50 meters around the springs. The vectors corresponding to the PPAs were associated with the land use and management of January 2011, allowing spatialization and quantification of the areas of land use/management in disagreement with Brazilian forest legislation, which advocates the preservation of native forest in these areas.

3. Results and discussion

The land use capacity classes of Ribeirão das Perobas Sub-Basin are spatialized in the *Figure 2*.

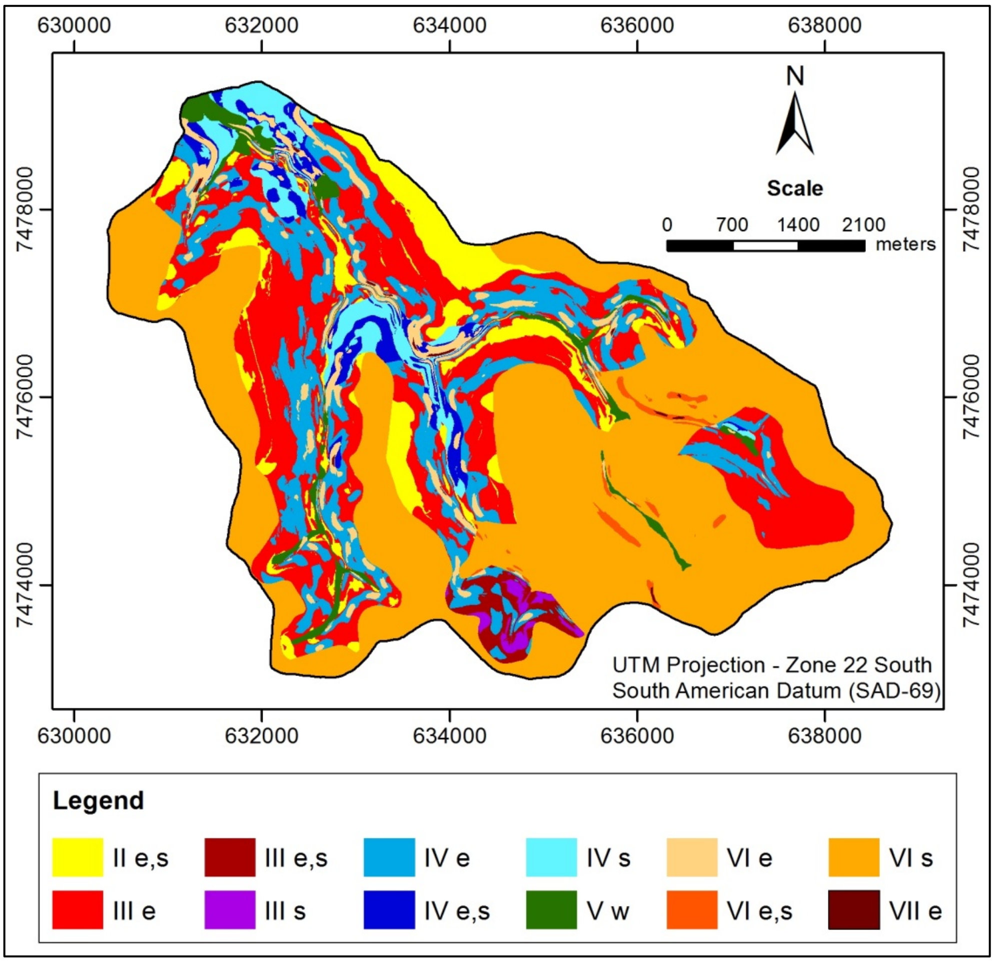

Figure 2. Land use capacity map of Ribeirão das Perobas Sub-Basin.

The lands of class VIs occupy 44.15% of the study area on Argissolos (Ultisols) and Latossolos (Oxisols) medium texture to clay. The lower slope classes predominate and the main limitation to farming use is the very low soil fertility. Lands of class VI are inappropriate for annual crops, but they can be grown with pasture, forestry and some permanent soil protective crops, if properly managed. The class of second largest area in the sub-basin is IIIe, representing 21.6% of its area. When located on Ultisols areas, the main limiting factor to farming use is the poor permeability and drainage and on Oxisols and Alfisols (Nitossolos) areas, the main limitation is the medium slope. Lands classified into this class are suitable for crops in general, but they require intense and complex measures for soil conservation to prevent it from the degradation risk.

The class VIe occupies 12.94% of the sub-basin and it is located on several soil types, being its main limitation for farming use the high slopes, which requires the adoption of mechanical practices for erosion control such as contour tillage and terracing. The class IIe,s occupies 7.16% of the sub-basin and it has the smallest limitation to farming use among the other classes, related to moderate fertility, presence of sheet and rill erosion, low to medium slopes and moderate to very slow runoff. The class Vw corresponds to areas of very poor permeability and drainage and occasional flood risk, mostly located in the valley bottom. The other land use capacity classes are negligible in the study area.

The *Figure 3* shows the land uses and agricultural managements of Ribeirão das Perobas Sub-Basin in January 2011.

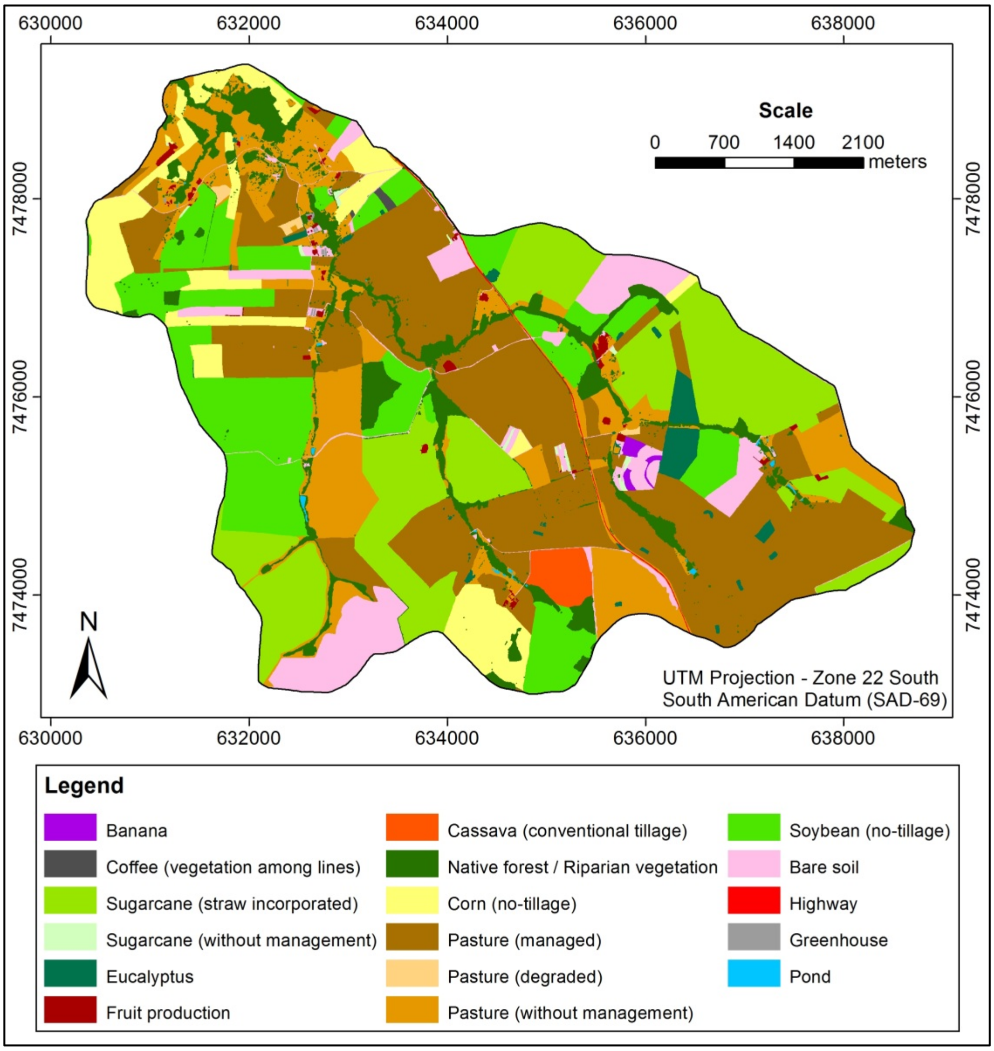

Figure 3. Land use and management of Ribeirão das Perobas Sub-Basin in January, 2011.

The managed pastures, i.e. terraced and/or fertilized areas with high density of land cover, occupy 29.96% of the sub-basin and have lower susceptibility to hydric erosion. The pastures without management represent 13.35% of the area, and the total area of pasture (managed, without management and degraded) represents 43.48% of the sub-basin area. The sugarcane crops with incorporation of straw from previous cycles occupy 539.13 hectares or 17.61% of the study area. Being a semi-perennial crop, it is generally less susceptible to erosion than annual crops, but part of sugarcane areas were mapped as bare soil because they have harvested before January 2011, the month of greatest rainfall in the region, resulting in higher susceptibility to erosion.

The main summer annual crops present in the sub-basin are soybean (14.39%) and corn (6.78%), both grown in no-tillage system. The native forest and riparian vegetation occupy only 7.41% of the study area, in the PPAs along rivers, around springs, steep slopes and low slope areas. This percentage is lower than that required by Brazilian Forest Code, which requires the maintenance of 20% of the farms area with native vegetation preserved, besides the PPA.

The conservation practices adopted in the sub-basin are mapped in *Figure 4*.

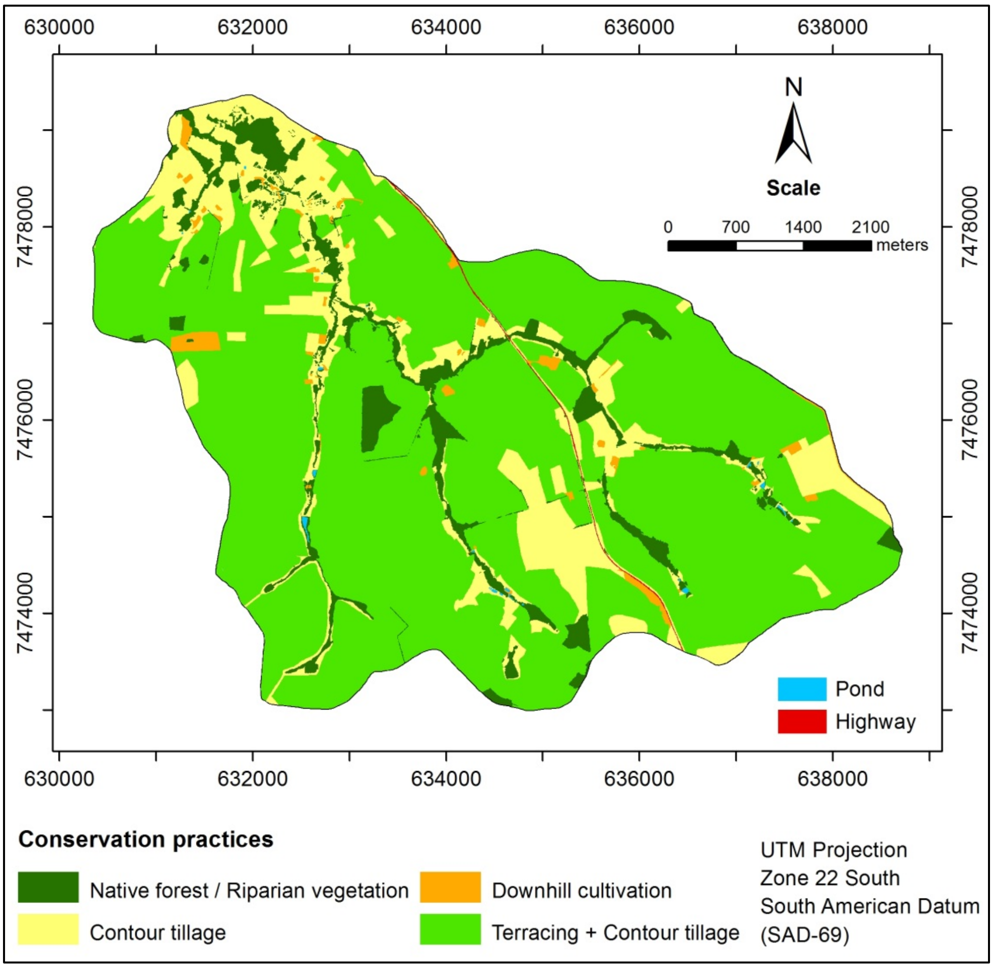

Figure 4. Conservation practices for erosion control in Ribeirão das Perobas Sub-Basin (January, 2011).

The map of conservation practices shows that 75.52% of the area (2,311.57 hectares) are managed with contour tillage and terracing to protect the soil against erosion; 15.76% of the area are only tilled and grown in contour; 1.30% is grown downhill, and the remaining areas are occupied by native vegetation, ponds and highway. Almost all the sugarcane crops, pasture and annual crops are terraced, and part of the pastures on low slope terrains do not require this conservation practice. The north and northwest portions of the sub-basin, however, have steep slopes, but they present only contour tillage or downhill cultivation.

The *Figure 5* shows the degree of adequacy of the land use and management of the study area to the land use capacity.

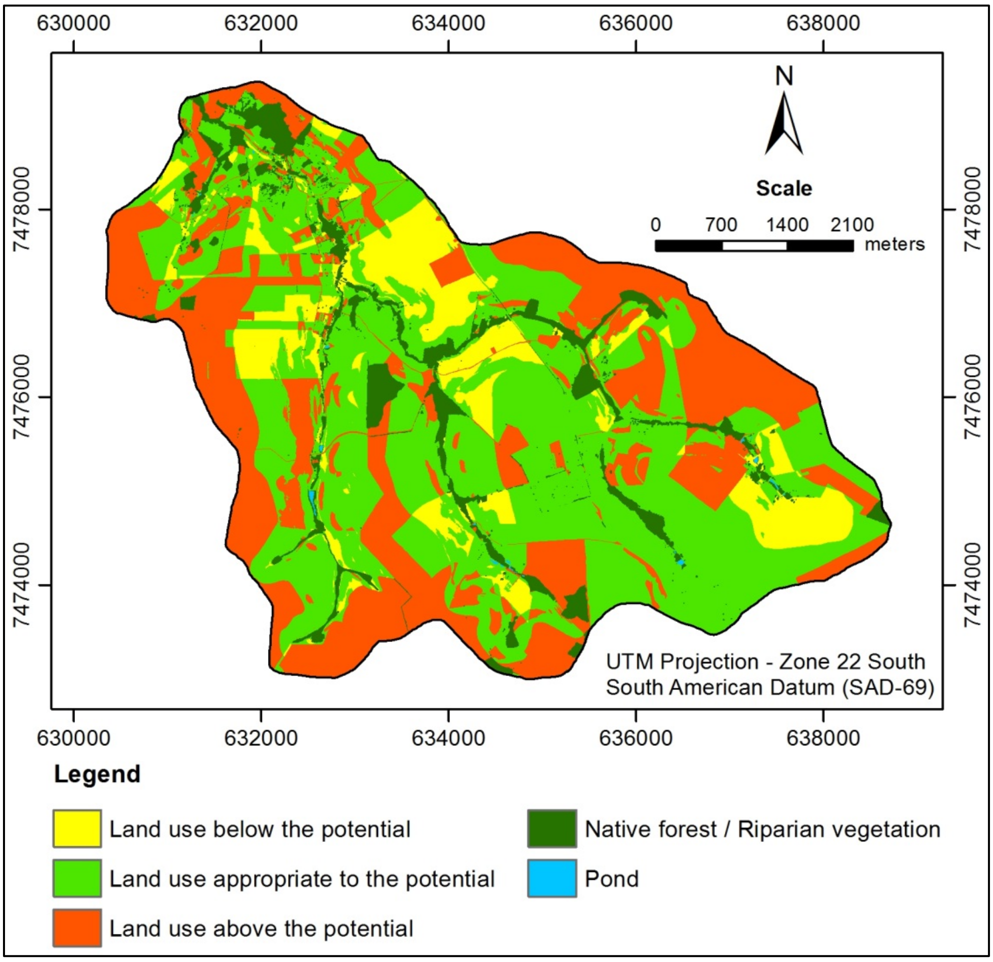

Figure 5. Degree of adequacy of the land use and management to the land use capacity in Ribeirão das Perobas Sub-Basin.

The map analysis and quantification of the area of land use and management adequacy classes to the land use capacity show that 11.6% of the study area have land use below the potential; 48.19% of the area are appropriate to the potential and 32.70% present land use above the potential for soil conservation, i.e. above the land use capacity. The remaining area is occupied by native forest, riparian vegetation and ponds.

The areas of land use capacity class VIs, which cover the largest area in the sub-basin, present land use above the potential in 695.63 hectares or 22.72% of the sub-basin, which represents 69.49% of the areas whose land use are above the land use capacity. The main limiting factor to agriculture is the very low soil fertility and the main crops in disagreement are: sugarcane, corn, soybean and cassava. The lands of class IIe,s and IIIe represent, together, 96.51% of the areas whose land use and management are below the potential, because they have the smallest limitations to farming use. Pasture, eucalyptus and fruit production are responsible for use below the potential.

The land use and management appropriate to the land use capacity occurs in lands of class VIs (40.88% of the areas of appropriate use, occupied by pasture, eucalyptus and fruit trees), IIIe (21.91% of the appropriate use, occupied by pasture without management and perennial, semi-perennial and annual crops), IVe (16.27% of the areas of appropriate use, grown with pasture and perennial crops), and others. The land use is above the potential in all bare soil areas, and the degree of adequacy decreases with the increasing land use capacity number from I to VIII in the following order of crops: annual crops, perennial crops, pasture, forestry and natural vegetation.

The *Figure 6* shows the degree of adequacy of conservation practices on agricultural lands of the sub-basin to the land use capacity.

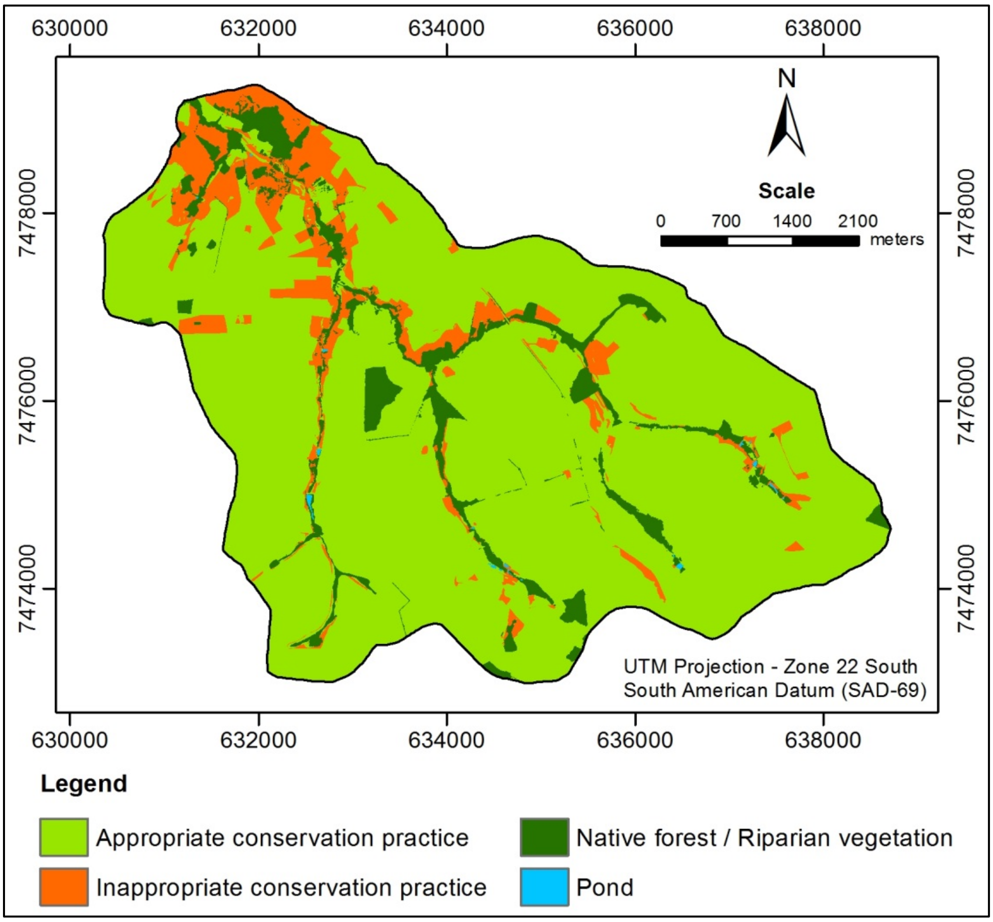

Figure 6. Adequacy of soil conservation practices to the land use capacity in Ribeirão das Perobas Sub-Basin.

The soil conservation practices adopted in the study area are appropriate to the land use capacity in 2,560.20 hectares or 83.64% of its area, and 278.90 hectares or 9.11% of the total area have inappropriate conservation practices, i.e. downhill cultivation or only contour tillage in areas whose use is limited by erosion risk or presence of erosion in steep slope areas close to the drainage network and in farming areas located in the northwestern sub-basin. The main land use capacity classes with inappropriate soil conservation practices are: IIIe, IVe and IVs.

90.28% of the agricultural areas whose conservation practices are appropriate to the land use capacity are tilled in contour and terraced. The remaining area presents only contour tillage or it is occupied by highway. In general, farming areas with contour tillage and showing appropriate conservation practices to the land use capacity have limitations related to soil fertility, flood risk or very poor drainage and permeability, and not on the slope.

The *Figure 7* shows the land uses and management in the PPAs of the sub-basin in January 2011.

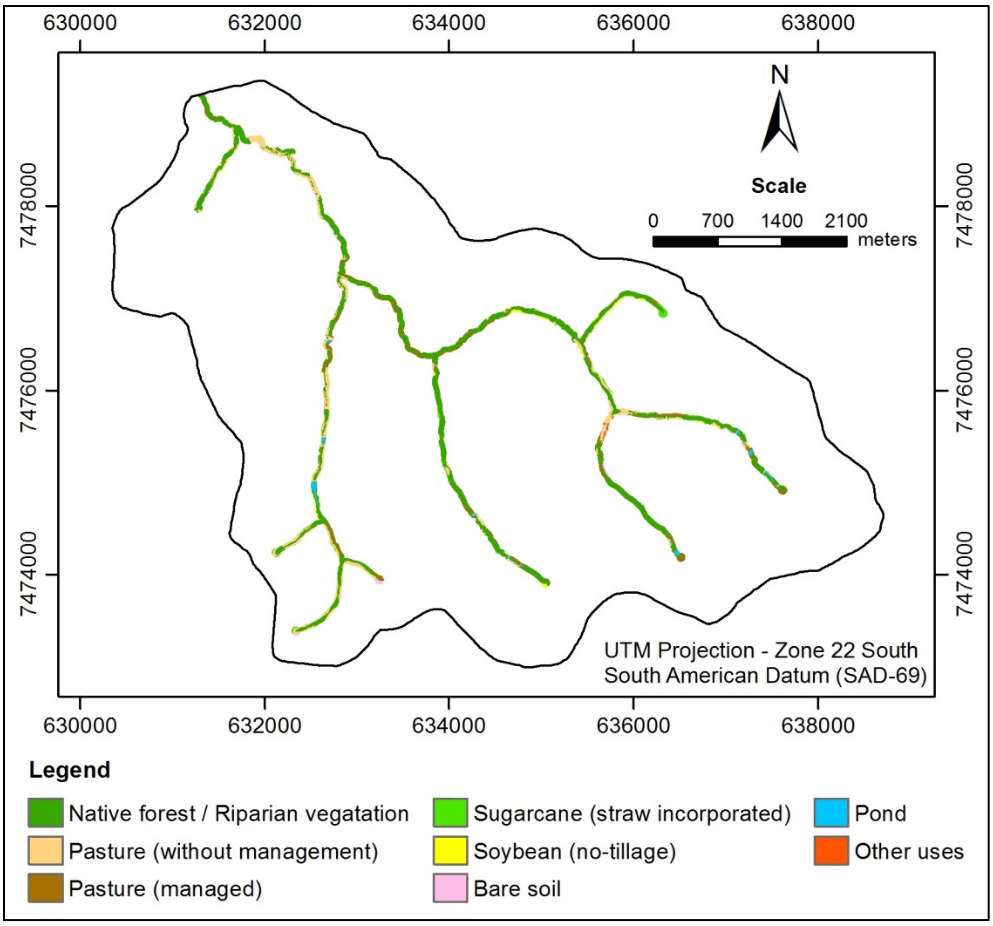

Figure 7. Land use and management in Permanent Preservation Areas of Ribeirão das Perobas Sub-Basin.

The map of PPAs of the study area shows that the land use and management are suitable to the Brazilian forest legislation, favoring the conservation of water resources, soil and aquatic ecosystems in 63.41% of PPA area, or 89.16 hectares, covered by preserved native forest and ponds. However, 36.59% of its area are in conflict with the forest legislation, mainly occupied by pastures, soybean, sugarcane, bare soil and other crops, which increases soil vulnerability to erosion, resulting in siltation of rivers and commitment of their water regime, threat to aquatic ecosystems and other environmental damages.

4. Conclusion

The analyzes made in this study through Remote Sensing imagery and GIS techniques allowed to conclude that 32.70% of the area of Ribeirão das Perobas Sub-Basin present land use/management above the potential, in disagreement with the land use capacity, and 11.60% of the study area present land use below the potential; regarding conservation practices, 9.11% of the study area are inappropriate to the land use capacity, especially in steep slope areas. The PPAs located along rivers present conflicting land use in 36.59% of their area not occupied by riparian vegetation or ponds. In these areas, soil degradation risk by erosion is greater, requiring a proper planning of agricultural occupation by farmers. The use of geotechnology was essential for map production and data crossing, enabling rapid integration of spatial data, the development of more accurate environmental diagnosis and the analysis of spatial distribution of environmental data.

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