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Erosion Risk Mapping Applied to Environmental Zoning

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Abstract Water erosion caused by inappropriate land use compromises the ecosystems and causes economic and social losses. To remedy this, the present study proposes (i) the evaluation of the erosion risk in an Environmental Protection Area (EPA) with the combination of Universal Soil Loss Equation (USLE), soil loss tolerance (T) estimates adapted to Brazilian soils and the legislation; and (ii) control measures from environmental zoning. This was applied to the EPA of Lageado stream, one of the main surface water sources in Campo Grande, Brazil. Several referenced information plans were overlapped and the total area was divided into five zones with different land use profiles, which were determined according to the conservation and preservation of native vegetation, occurrence of wet areas and springs, land use and management, eroded area recovery and occurrence of permanently preserved areas. The methodology proposed was suitable for environmental zoning of protected areas. This protocol can be applied to other areas by including additional variables such as social and economic parameters.

Keywords Water erosion · Soil loss tolerance · Water and soil management · Geographical information system · Remote sensing

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1 Introduction

Water erosion is a primary cause of environmental degradation that can affect both soil and water. A wide range of damaging effects involve not only the farming aspects (profitable crop production), but also the concerns of society related to environmental degradation (e.g. impacts on fresh water resources) and food security (degradation of the non-renewable natural resource soil, essential for crop production) (Sparovek and De Maria 2003). This process has been accelerated mainly by inappropriate land use (Nearing et al. 2005).

The state of Mato Grosso do Sul is one of the most important Brazilian states in terms of water resources because it includes the Parana and Paraguay basins and the Guarani aquifer (Gastmans et al. 2010). In parallel, agriculture is the main economic activity in this region, with predominance of extensive livestock farming. Because of the poor management of pastures, water erosion poses a threat to these areas (Sparovek et al. 2007). The Environmental Protection Area (EPA) of Lageado, located at Campo Grande city (capital of state Mato Grosso do Sul), contains important surface waters that supply nearly 75,000 individuals. In this area the water erosion is considered a main form of environmental degradation. Therefore, adequate land use should be a priority for soil and water conservation (Pandey et al. 2007). In fact, planning, conservation and management of watersheds is vital to avoid erosion and to protect the water resources

Land use zoning facilitates environmental planning and management because each zone is determined according to its conditions, e.g. critical or environmentally vulnerable. Factors associated to soil loss are among the main variables used for soil conservation planning. These variables are used to isolate and describe areas that are vulnerable to erosion and to guide the immediate conservation measures to be adopted at specific sites (Lee 2004).

Soil loss tolerance values have been used to determine permissible soil loss before land degradation. This variable can be adjusted to erosion models according to the study area, thereby allowing standardization of agroecological zoning (Bhattacharyya et al. 2008). The current situation of an erosive process must also be analyzed to identify areas with erosion risk and determine the type of conservation practice to be applied (Irvem et al. 2007). Based on a 5-year study, Basic et al. (2004) suggest the use of erosion risk as an indicator of land use sustainability. Erosion risk values have been used for agricultural and environmental planning worldwide because they identify areas with critical soil loss (Zhang et al. 2004; Basic et al. 2004).

Erosion modeling techniques allow the assessment of erosion damage to agricultural soil and water resources (Renschler and Harbor 2002), thereby providing useful information for decision making concerning water and soil conservation planning (Schiettecatte et al. 2008). The Universal Soil Loss Equation (USLE) proposed by Wischmeier and Smith (1978) is an empirical predictive model for soil erosion that has been integrated into Geographic Information Systems (GIS) worldwide (Lufafa et al. 2003; Dabral et al. 2008; Wang et al. 2009; Jain and Das 2010). The USLE has some limitations as a prediction model, because this equation predicts the total soil loss (rill erosion and interrill erosion) without differentiating between each of these components. Furthermore, it does not include soil loss as a result of gully formation nor estimates sediment deposition in specific areas. An additional limitation of the USLE is that it requires long-term data to develop the parameters for climate (R factor) and erodibility (K) factor for locations and soils outside the original dataset. In developing countries in particular, these long-term erosion plot data are often not available. The USLE, although its limitation, it is considered a satisfactory model for soil and water conservation planning (Ozcan et al. 2008; Beskow et al. 2009; Chou 2010).

The present study proposes (i) the evaluation of the erosion risk in an EPA with the combination of USLE, soil loss tolerance (T) estimates adapted to Brazilian soils and the legislation; and (ii) control measures from environmental zoning. This methodology was applied to the EPA of Lageado stream, Brazil, and can be further applied in the management planning of protection areas and hydrographic basins to promote adequate land use and occupancy, preservation of environmental resources and improvement in agricultural productivity.

2 Material and Methods

2.1 Study Area

This study was conducted in the Environmental Protection Area (EPA) of Lageado, Brazil. This EPA contains important surface waters that supply nearly 10% of the inhabitants of Campo Grande city, Brazil. This area encompasses approximately 53 km^2 and includes the hydrographic basin of the Lageado stream from the surface water collection point (latitude 20°31′ S and longitude 54°33′ W). Figure 1 shows the area's location.

The study area belongs to a larger geological unit called Paraná Sedimentar Basin. According to the Köeppen classification, climate in this area is in the transitional stage between Cfa, humid mesothermal with no dry season, and AW, humid tropical with a rainy season in the summer and dry season in the winter. The rainfall in the driest month (July) and wettest month (January) is 30 mm and 213 mm, respectively. Altitude in the area ranges from 550 m at the water collection point to 694 m north of the watersheds. The relief is mainly flat with 0–6% slope.

2.2 Universal Soil Loss Equation (USLE)

The USLE was used to estimate soil loss from sheet and rill erosion (Wischmeier and Smith 1978) using GIS SPRING 4.3.3 (Câmara et al. 1996). Each factor defined by the USLE was developed in spatial language algebraic geoprocessing by the SPRING software.

As proposed by Wischmeier and Smith (1978), the USLE model calculates mean annual soil loss (A), in tons per hectare, integrating 6 factors (Eq. 1):

$$A = R \,.\, K \,.\, L \,.\, S \,.\, C \,.\, P \tag{1}$$

where: A is the average annual soil loss per unit of area (t ha^{-1} $year^{-1}$), R is the rainfall–runoff erosivity factor (MJ mm ha^{-1} h^{-1} $year^{-1}$), K is the soil erodibility factor (t h MJ^{-1} mm^{-1}), LS is the topographic factor (dimensionless), C is the cover-management factor (dimensionless), and P is the support practice factor (dimensionless).

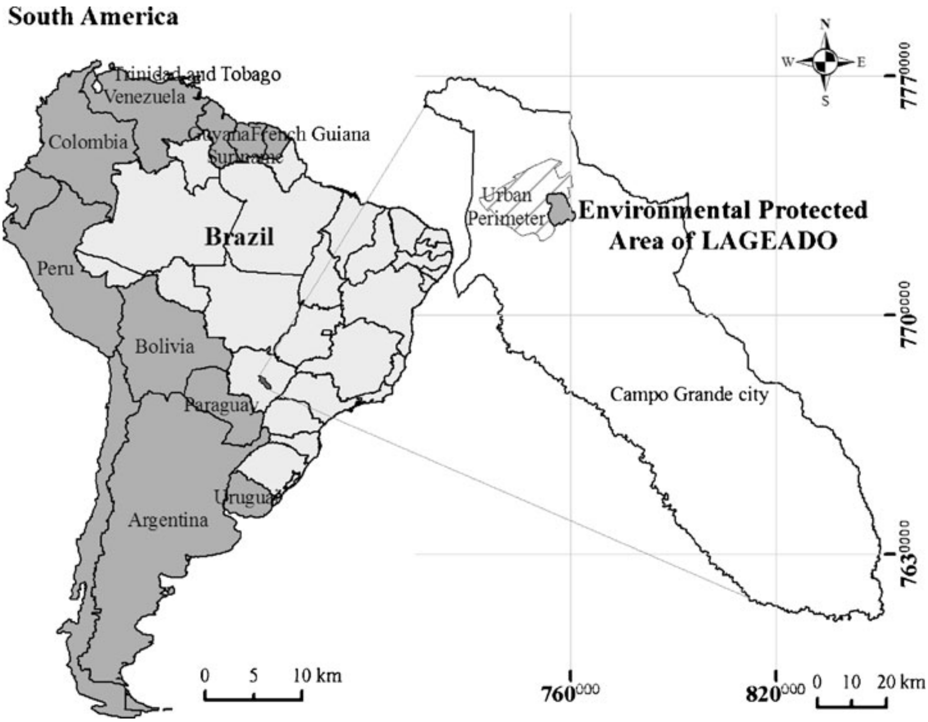

Fig. 1 Study area location

2.3 Average Annual Erosivity Index

A series of daily rain gauge measurements recorded from 2002 to 2008 was used to calculate the R factor. These measures were taken in a single pluviograph station, with historical series of less than 20 years, minimum series required by USLE calculation, because in Brazil, in general, the historical climate information is scarce and difficult to access (Montebeller et al. 2007).

Isolated rainfalls were classified as either erosive or non-erosive. We considered rainfalls to be isolated and non-erosive when they were separated from others by precipitation between 0 (no rain) and 1.0 mm for at least 6 h, and erosive when 6.0 mm of rain fell in 15 min or 10.0 mm over a longer period. Erosivity was calculated using the EI_{30} index (Wischmeier 1959), which is the product of maximal precipitation in 30 min (I_{30}) and rain kinetic energy provided by the International Unity System (Foster et al. 1981). The USLE R factor was obtained by the average of annual values the EI_{30} erosion index, and it was considered uniform for the study area.

2.4 Soil Erodibility and Soil Loss Tolerance

Soil erodibility (K factor) can be assessed by direct and indirect methods. The direct procedure needs natural and simulated rainfalls measured in standard 22 m-long plots with slope steepness of 9%, whereas the indirect procedures correlate data

Table 1 Factor ‘ra’ in accordance with textural relation (TR) of clay between B and A horizons and clay content in the horizon A

TR	Clay content in the horizon A		
(% clay horizon B)/(% clay horizon A)	>40%	40–20%	<20%
<1.5	1.0	0.9	0.8
1.5–2.0	0.8	0.7	0.6
>2.0	0.6	0.5	0.4

Source: adapted from Bertol and Almeida (2000)

obtained by the direct method to soil properties (Zhang et al. 2008). In the present study we obtained K by the indirect method using the nomograph developed by Wischmeier et al. (1971). This nomograph considers characteristics such as texture, permeability, organic matter content and soil structure.

Soil loss tolerance (T) is defined as the amount of soil that can be lost without a long-term decline in crop productivity (Wischmeier and Smith 1978). Reduction of topsoil depth decreases crop productivity (Li et al. 2009). The first Brazilian studies on soil loss tolerance were carried out by Lombardi Neto and Bertoni (1975) in soils of the state of São Paulo and focused on the effective soil depth and textural relation of superficial horizons. Complimentarily, Galindo and Margolis (1989) investigated the organic matter content and the degree of soil permeability. Bertol and Almeida (2000) assigned values to organic matter and permeability factors. This last proposal is the most widely used in studies on soil loss tolerance in Brazil.

Soil loss tolerance was obtained using the method proposed by Bertol and Almeida (2000) (Eq. 2).

$$T = h \,.\, ra \,.\, m \,.\, p \,.\, d \,.\, 1{,}000^{-1} \,.\, 100 \quad (2)$$

where: T = soil loss tolerance in thickness ($t\ ha^{-1}\ year^{-1}$); h = effective soil depth (cm), limited to 1.0 m; ra = textural relation of clay between B and A horizons and clay content in the A horizon (nondimensional) (Table 1); m = organic matter content in the top 0–20 cm layer (nondimensional) (Table 2); p = soil permeability factor (nondimensional) (Table 3); d = soil density ($g\ cm^{-3}$); 1,000 = constant value for time (years) spent to remove a 1.0 cm thick layer of soil; 100 = conversion factor unity.

Soil classes were determined according to a soil mapping update from the soil map of Campo Grande (scale 1:50,000) (Brazil 1982; Planurb 1991). We determined erodibility and soil loss tolerance values for each soil type detected in the study area.

Table 2 Factor ‘m’ in accordance with the organic matter content in the 0–20 cm soil depth

Organic matter content	Factor m
>2%	1.00
1 and 2%	0.85
<1%	0.70

Source: adapted from Bertol and Almeida (2000)

Table 3 Soil permeability classes ‘p’ in accordance with the structure and texture degree

Texture	Structure degree		
	Week	Moderate	Strong
Thin (clay > 35%)	Slow	Slow	Moderate
Average (15% < clay < 35%)	Moderate	Moderate	Fast
Thick (sand e loamy sand)	Moderate	Fast	Fast

Slow ($p = 0.70$); moderate ($p = 0.85$); fast ($p = 1.00$). Source: adapted from Bertol and Almeida (2000)

2.5 Topographic Factor (LS)

The L factor (slope length) and S factor (slope steepness) are treated separately in USLE, but when analyzed together they are called topographic factor LS. This combination of land steepness and slope length expresses relief relationships with soil loss. These are the main determinants of runoff speed and characteristics such as particle size and transport potential.

To obtain the LS factor we produced a Digital Elevation Model (DEM) by creating vectorial data on 1:100,000 scale topographic maps of Campo Grande and Sidrolândia, represented by 40 m-equidistant contour lines, point features and stream network. DEM was developed in the GIS SPRING software (Câmara et al. 1996) using vectorial samples to produce a triangular grid and a 30 × 30 m rectangular grid. This DEM was analyzed using USLE-2D software (Desmet and Govers 1996) to calculate the LS factor, in accordance with Oliveira et al. (2010).

The L factor was produced by applying Eq. 3 as proposed by Desmet and Govers (1996).

$$L_{i,j} = \left[\left(A_{i,j} + D^2 \right)^{m+1} - \left(A_{i,j} \right)^{m+1} \right] \Big/ \left[x_{i,j}^{m} . D^{m+2} . (22, 13)^{m} \right] \tag{3}$$

where: $L_{i,j}$ = slope length factor for a grid cell with coordinates *i, j*; $A_{i,j}$ = contributing area (m^2) for a grid cell with coordinates *i, j*; D = grid size (m); $x_{i,j}$ = outflow direction for that grid cell; and m: slope exponent.

USLE-2D software provides different algorithms to calculate the LS association (Wischmeier and Smith 1978; McCool et al. 1987, 1989; Govers 1991; Nearing 1997). We applied the algorithm proposed by Wischmeier and Smith (1978). Therefore, the *m* exponent in Eq. 3 consists of slope steepness variations, in which: $S < 1\%$ $m = 0.2$; $1\% \leq S \leq 3\%$ $m = 0.3$; $3\% < S \leq 5\%$ $m = 0.4$; and $S > 5\%$ $m = 0.5$.

We used Eq. 4, proposed by Wischmeier and Smith (1978), to calculate the S factor.

$$S = 65.41 \sin^2 \theta + 4.56 \sin \theta + 0.065 \tag{4}$$

where θ is the slope angle (%).

2.6 Use and Management Factor and Conservation Practices

Land use and management (C factor) reflect the relationship between soil loss from land cropped under specific conditions and the corresponding continuously cleaned land (Wischmeier and Smith 1978). This factor depends on soil cover, crop sequence, productivity level, harvest period and crop residue management practices.

To map land use we relied on the visual interpretation of images captured from the CBERS 2B satellite on 9 July 2008 with a High Resolution Camera (HRC) sensor. This HRC sensor operates in a spectral range of 0.50–0.80 μm (panchromatic) and spatial resolution of 2.7 m (INPE 2008). This data was validated in the field. We divided the mapped areas into 8 classes of land use and attributed a C factor value to each one (Table 6).

Areas covered by grassland, usually in empty public flowerbeds and lots, were classified as pasture and received the same C factor value. We assigned a value of 1 to the P factor because of the nonexistence of conservation practices in the study area.

2.7 Integration of USLE Factors

Based on the USLE factors obtained, we converted thematic data into numerical grids with 30 × 30 m resolution. We subsequently performed syntactic sequences using spatial language for algebraic geoprocessing fit to the proposed equations.

According to Wischmeier and Smith (1978), soil loss value (A) in USLE can be replaced by soil loss tolerance (T) in t ha^{-1} $year^{-1}$. Therefore, considering $P = 1$, we can estimate permissible land use and management (Eq. 5).

$$CP_p = T/R\,.\,K\,.\,L\,.\,S \quad (5)$$

This equation allowed the determination and analysis of the occupied land areas. We considered this index as an indicator of the probable adjustment in land use according to environmental characteristics that affected the erosive processes.

To identify the areas with excessive T values for each soil type, we calculated the ratio between soil loss and tolerable soil loss values. This is called erosion risk (ER) (Eq. 6).

$$ER = A/T \quad (6)$$

After the equation was applied we defined the ER classes: very low (<0.2); low (0.2–0.5); moderate (0.5–1.0); high (1.0–2.0); very high (2.0–4.0); and extreme (>4.0), as proposed by Basic et al. (2004).

The procedural sequence for action proposals within the environmental plan is shown in Fig. 2. The ER values indicate the level of environmental degradation, while the CP_p value guides the planning of corrective measures for areas in which we identified some degradation level.

2.8 Environmental Zoning

The criteria used for environmental zoning was the conservation and preservation of soil and water resources in the study area. Thus, we integrated the information plans: permissible land use; erosion risk; current land use; and legislation related to Areas of Permanent Preservation (APP).

Current soil occupation was used to identify the areas and elaborate conservation and preservation proposals for wet areas and those with native vegetation, denominated Zone 1.

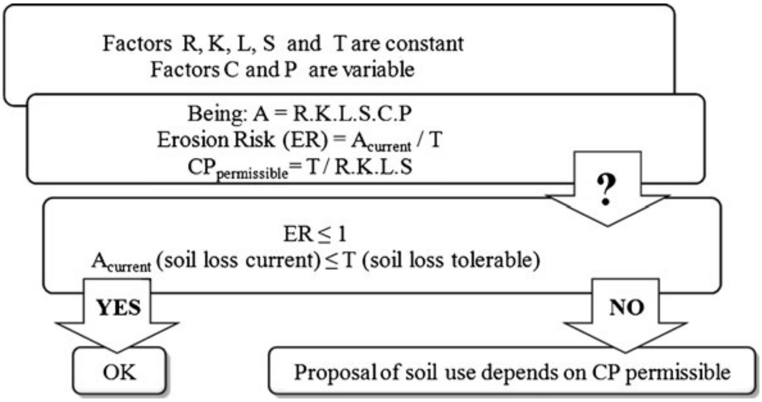

Fig. 2 Logical sequence for land use planning

Zone 2 comprised recovery areas in the APPs, i.e., areas that should be APPs but are irregularly occupied. The APPs were defined according to Brazilian Forest Legislation, which states certain areas, because of their importance for preserving the environment and water resources. Hilltops and hillside properties with an incline steeper than 45° ($S > 45°$) and areas adjacent to natural or artificial reservoirs and rivers are considered APP. The Brazilian Forest Legislation establish that the riparian vegetation must be preserved in: i) 30 m width of each margin for streams up to 10 m width; ii) 50 m width of each margin for streams from 10 to 50 m width; iii) 100 m width for rivers from 50 to 200 m width; iv) 200 m width for rivers from 200 to 500 m width; and v) 500 m for rivers higher than 600 m width. Therefore, a 30-m width buffer zone was marked around the watercourses and a 50-m width zone around springs and wet areas. We did not consider hilltop APPs, because hills with $S > 45°$ do not occur in the study area.

Erosion risk analysis was performed to identify areas that are degraded by soil erosion and require immediate recovery. These areas were classified as Zone 3 and had ER values over 1, i.e., the predicted soil loss was higher than the tolerable value ($ER > 1$).

The CP_p values were divided into 2 classes according to cropping activities (Zones 4 and 5). CP_p values in Zone 4 ranged from 0.1 to 1.0. In this area, perennial and annual cropping as well as cattle management and pasture areas were allowed. CP_p ranged from 0 to 0.1 in Zone 5. The areas included in this zone should have good soil coverage and management because they are currently under the highest threat from

Table 4 Proposal for environmental zoning

Zones	Name
1	Vegetal maintenance and preservation and wet areas
2	APP recovery (defined according to Brazilian Forest Legislation)
3	Recovery of areas degraded by soil erosion (ER values > 1)
4	Agricultural land used for annual crops (resistant areas)
5	Agricultural land used for pasture with regular management (fragile areas)

natural erosion. Zone 5 can have areas covered with perennial cultures and pastures with regular management.

After each zone was demarked, we grouped and quantified them to produce an environmental zoning map of the study area. The zones identified according to land use are summarized in Table 4.

3 Results and Discussion

The rainfall erosivity value was equal to 6,515 MJ mm ha^{-1} h^{-1} year^{-1} (Fig. 3a). Based on data from 1,600 rain gauge stations throughout Brazil, Silva (2004) found erosiveness values from 3,116 to 20,035 MJ mm ha^{-1} h^{-1} year^{-1}. Therefore, the erosiveness we recorded can be classified as moderate.

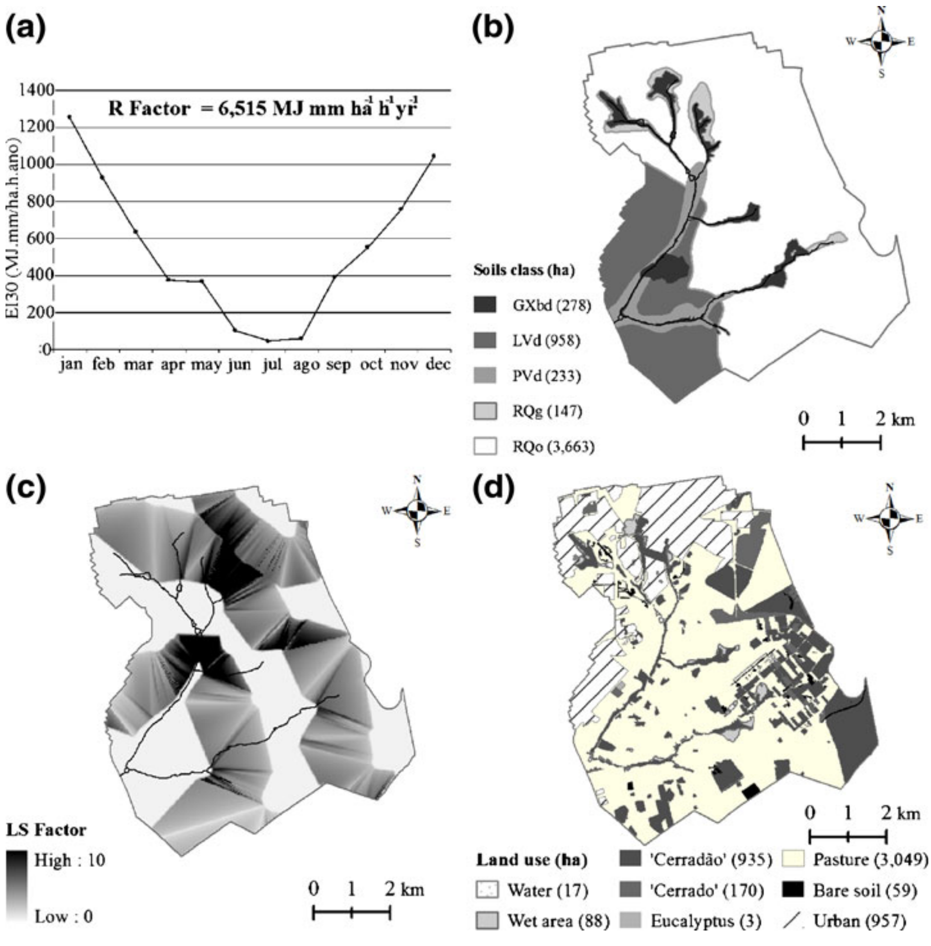

Fig. 3 Components of the USLE model: **a** erosiveness (R factor); **b** erodibility (K factor); **c** topographic conditions (LS factor); **d** land use and management (C factor)

Table 5 Soil classes, erodibility and soil loss tolerance

Soil classes	Erodibility (K) t h MJ^{-1} mm^{-1}	Tolerance (T) t ha^{-1} $year^{-1}$
Ortic *Quartzarenic* Neosol (RQo)	0.0270	8.2
Hydromorphic Quartzarenic Neosol (RQg)	0.0270	7.5
Dystrophic Red Latosol (LVd)	0.0130	15
Dystrophic Red Argisol (PVd)	0.0330	8.5
Dystrophic Tb, Haplic Gleisol (GXbd)	0.0355	7.5

Soil types in the Lageado EPA have different erodibility characteristics. Nearly 69% of the EPA is covered with ortic Quartzarenic Neosol (RQo), which has moderate erodibility. Soils with high erodibility, such as the Dystrophic Red Argisol (PVd) and the Dystrophic Tb, Haplic Gleisol (GXbd), covered around 10% of the area. Soils that are less susceptible to erosion, such as the Dystrophic Red Latosol (LVd) in the southwest portion of the study area, cover 18% of the area (Table 5 and Fig. 3b).

The soil loss tolerance values obtained (Table 5) were found inside the value range obtained by other studies achieved in Brazil. The Brazilian tolerance values are: 4.5–15.0 t ha^{-1} $year^{-1}$ for soils of São Paulo State (Lombardi Neto and Bertoni 1975); 1.1–12.3 t ha^{-1} $year^{-1}$ for soils of Pernambuco State (Galindo and Margolis 1989); 1.88–14.50 t ha^{-1} $year^{-1}$ for soils of Santa Catarina State (Bertol and Almeida 2000).

The topographic factor ranged from 0 to 10 (Fig. 3c). The highest values were concentrated in the north portion of the study area, which exhibits higher steepness (4–8%).

The EPA land is predominantly covered by pasture (57.8%), 'cerradão' (17.7%), 'cerrado' (3.2%), eucalyptus (0.1%), water (0.3%), wet area (1.7%), exposed soil (1.1%) and urban area (18.1%) (Fig. 3d). 'cerradão' and 'cerrado' together represent 20.9% of the area covered with native vegetation. The 'cerradão', or savanna woodland has an almost closed canopy (50–90% tree cover and 8–15 m tree height). The 'cerrado' vegetation (sensu stricto) or woody savanna has sparse distribution (20–50% tree cover and 3–6 m tree height) (Ferreira and Huete 2004). The values of C factor for each land use are presented in Table 6.

Beef cattle farming is the predominant activity in the area. However, small farms raise dairy cattle and other animals (pigs, goats and sheep) in addition to growing vegetable crops. Some EPA portions are also used as fish farms, for which land owners commonly deviate or dam stream waters to supply the tanks.

Table 6 C factor value according to land use

Classes	C factor
Water	0
Wet area	0
'Cerradão'	0.001
'Cerrado'	0.002
Eucalyptus	0.005
Pasture	0.01
Exposed soil	1
Urban area	0.03

Source: adapted from Wischmeier and Smith (1978)

3.1 Soil Loss and Permissible Land Use

Mean soil loss index (± sd) in the study area was 2.0 ± 10.6 t ha^{-1} $year^{-1}$. The high deviation indicates the variability of this index. This occurred because 96% of the results indicate soil loss of less than 7.5 t ha^{-1} $year^{-1}$, whereas the remaining data represent high soil loss (Fig. 4a).

In spite of we used the USLE factors adapted for this region, the erosion prediction of this model leads to some uncertainties. Which has been observed on the results from the USLE/RUSLE, that these models tend to over-predicts small annual average erosion and under-predicts large annual average erosion (Risse et al. 1993; Kinnell 2010), although more process-based models like Water Erosion Prediction Project (WEPP) do the same (Tiwari et al. 2000; Amore et al. 2004). However, soil loss over a long period of time (and a larger area) might be estimated correctly on the basis of the USLE methodology, because overestimations and underestimations can compensate each other, resulting in a good overall assessment of total soil loss (Gabriels et al. 2003).

Management plans for the areas that obtained values of permissible land use close to 0 (Fig. 4b) should focus on the maintenance of plant coverage as well as regular soil management. The areas that obtained values over 0.5 are more resistant against erosion, and support intense cultivation associated to annual crops.

The southeast area of the EPA (Fig. 4b) has the highest natural resistance against erosion because it combines a soil type with high soil loss tolerance values (LVd) and low values for the topographic factor. The north area (Fig. 4b) has the most fragile soil and may have CP values close to 0. Soils from the neosol group, characterized by low soil loss tolerance values, predominate in this area.

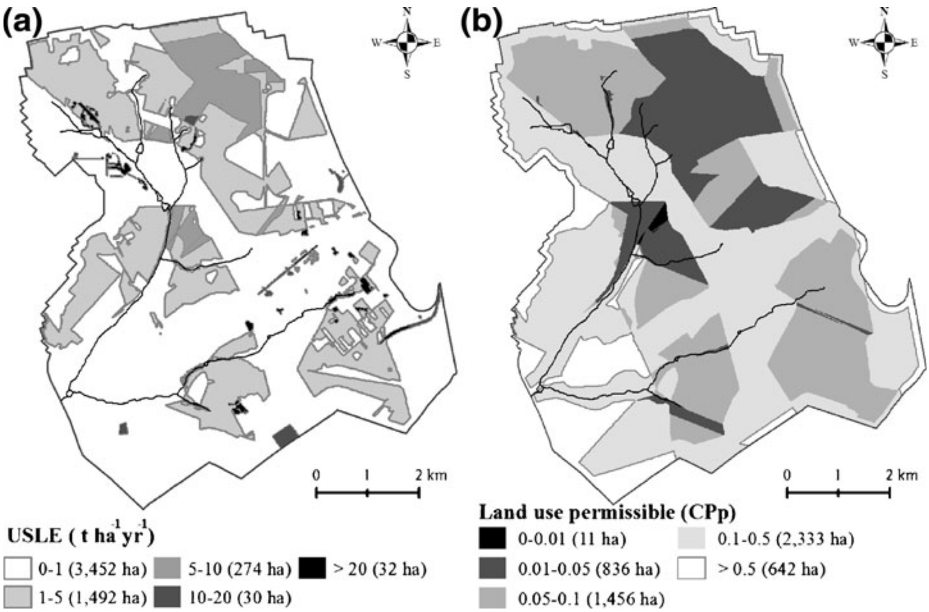

Fig. 4 **a** Spatial distribution of soil loss and **b** Permissible land use in the Lageado EPA

3.2 Erosion Risk

Erosion risk classes in the study area are as follows: very low (80.9%), low (11.1%), moderate (5.5%), high (1.6%), very high (0.4%) and extreme (0.5%). Risk classes from high to extreme represent 2.5% of the EPA. Because they have soil loss above the tolerable limit, they must be the first to be considered for recovery operations in local planning.

Erosion risk is minimal near the water reservoir in the south area of the map (Fig. 5). In contrast, the springs in the north area of the map are surrounded by areas of high erosion risk. The excessive sediment production in these areas may compromise the quality and quantity of water for downstream users, thereby decreasing reservoir lifetime for public water supply.

3.3 Environmental Zoning

Zone 1, which comprises 22.7% of the area includes portions of vegetation maintenance, wet sites and springs. This zone is crucial to the ecological equilibrium of the study area. Maintenance of native vegetation along with recovery of APP are essential to reduce erosion (Asis and Omasa 2007) and to form a natural physical

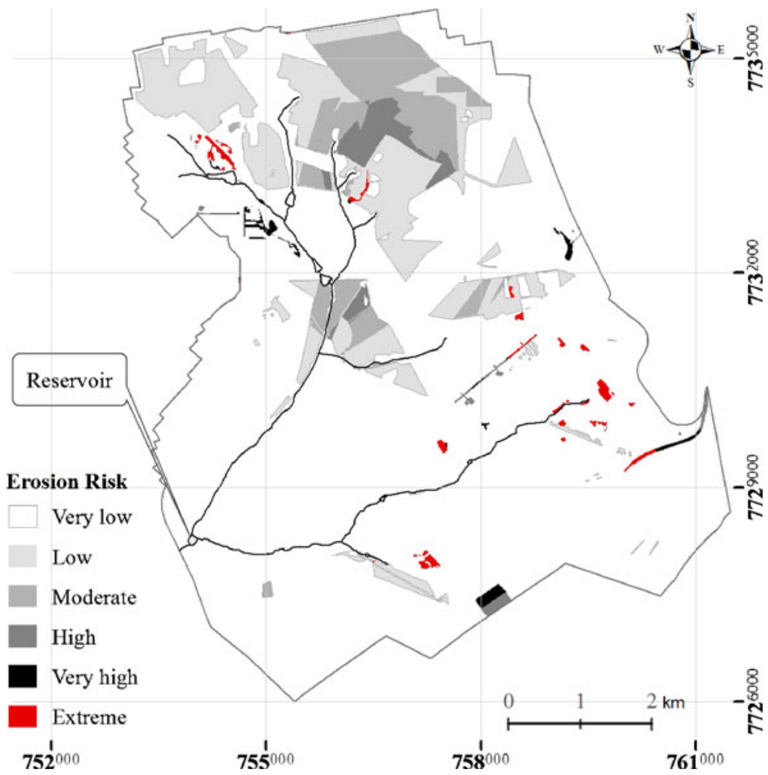

Fig. 5 Erosion risk map

barrier that retains lixiviation and agrochemicals (Casalí et al. 2008). Some studies reveal that degradation of riparian vegetation can affect stream channel morphology, erosion rates and sediment deposition (Silva et al. 2007). The APP was replaced by pastures in the area surrounding the water collection reservoir. Therefore, the APP must be recovered and fenced to avoid animal incursions so that water quality and hydraulic management of the reservoir are not compromised.

The recovery areas (Zones 2 and 3) cover 5.2% of the Lageado EPA (Fig. 6). These areas require investments in recovery measures. This is necessary to avoid exacerbating existing problems, such as soil fertility loss, stream siltation, decreased water volume in the reservoir and compromised water quality, which can become improper for human consumption.

Our zoning proposal designates two zones in the EPA for agricultural use. The first, Zone 4, covers 41.1% of the EPA and is more resistant to erosion. Annual crops, requiring soil management, can be grown. In contrast, Zone 5 (represents about 31% the EPA) contains areas that are more susceptible to erosion and demand coverage and regular soil management. These areas should be planted with perennial crops or regularly managed pastures.

Parts of Zones 3, 4 and 5 are occupied by unpaved urban areas, a situation that promotes soil loss. Therefore, the public sector should concentrate its actions for reorganize anthropogenic activity in critically eroded areas (Zone 3) and areas that are more susceptible to erosion (Zone 5), thereby minimizing the risk of soil and water degradation in the urban area.

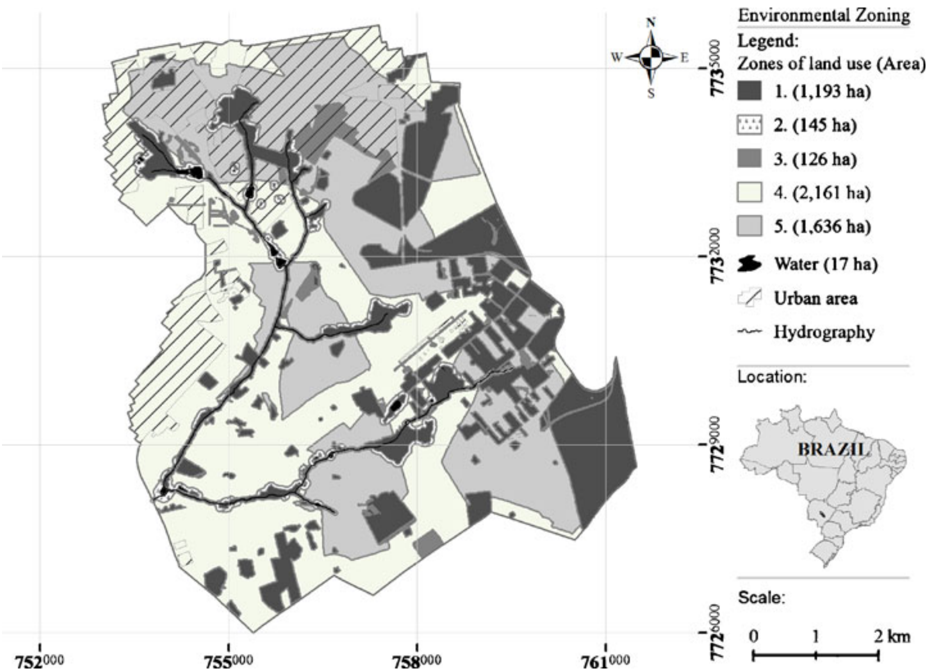

Fig. 6 Environmental zoning of lageado EPA

4 Conclusion

The methodology used in this study may be a tool in environmental zoning. It can be applied to other environmental protection areas and hydrographic basins. We did not incorporate social and economic factors into the model. These variables can be included in future studies for a better fit to environmental and socioeconomic requirements of the areas studied.

The environmental zoning proposed allows the determination of land use zones and, consequently, the identification of irregularities and conservation priorities. This can be used for better financial resources distribution in environmental management units to improve conservation and preservation outcomes and increase agricultural production.

Nearly 2.5% of the study area, classified as high and extreme erosion risk, has soil loss above the tolerable limits. Therefore, recovery of these areas is a priority to be considered in the environmental plan. To improve farm land management, constant monitoring and additional studies should be carried out and technical assistance provided to the farmers.

According to the environmental zoning proposed, land use should change at the areas with soil loss above the tolerable value and in the cases of human activity occurrence in APPs.

The implementation of environmental zoning in the study area is needed, especially considering the increasing demand for good quality multiple purpose water. This measure can be funded by environmental agencies.

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