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Environmental fragility and vegetation cover dynamics in the Lapa Grande State Park, MG, Brazil

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Abstract: The environmental fragility analysis evaluates the susceptibility of an environment to degradation. Thus, the goals of this work are to analyze and map the environmental fragility of the Lapa Grande State Park (PELG), Brazil, and its buffer zone (ZA) and also quantify the changes in the vegetation cover before and after the implementation of the PELG. The environmental fragility was evaluated through multicriteria analysis using the factors: slope, geology, pedology and land use and land cover. The changes in the high vigor vegetation cover were determined from the normalized difference vegetation index (NDVI) for 1996, 2006 and 2016. It was verified that the central-east and northeast regions of the PELG presented the greatest environmental fragilities in 1996, and significant reductions in the areas with high and very high fragility were observed in 2006 and 2016 due to the increase in the vegetation cover after the implementation of the PELG, which was more expressive in the park area than in the ZA. The increase of 20.7% of 2006 to 2016 in the vegetation with greater vigor, proved the importance of the creation of a conservation unit.

Key words: environmental fragility, environmental management, Lapa Grande park, multicriteria analysis.

INTRODUCTION

Aggregating economic development with environmental conservation is a major challenge for humanity. Population growth has increased the demand for natural resources and, along with indiscriminate anthropogenic activities, it has accelerated environmental degradation, including the degradation of areas considered protected and essential for biodiversity preservation (Nandy et al. 2015).

The consequences of the exploitation of natural resources may be variable. The impact that is generated depends on the degree of exploitation and the resistance of the environment to recovery, which can lead to damages such as erosion, landslides and flooding (Dalla Corte et al. 2015).

To understand and quantify the relationship between human activity and environmental quality, environmental fragility models have been created, which have become a valuable tool for decision makers and planning development policies (Manfré et al. 2013, Tran et al. 2010). Thus, this analysis of environmental fragility

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investigates the susceptibility of an environment to a change in its natural balance. Thus, it evaluates the environmental vulnerability to degradation, especially the potential to trigger erosive processes and sedimentation, an important evaluation in projects for environmental planning (Cardoso et al. 2015, Macedo et al. 2018, Valle et al. 2016).

In Brazil, based on the ecodynamic units of Tricart (1977), in which natural environments have a dynamic equilibrium between the energy and matter exchange and become unstable with the actions that cause imbalance, the Ross (1994) methodology was developed. According to Ross (1994), the analysis of environmental fragility takes into account the survey aspects of geomorphology, pedology, climate and land use and land cover. The first three aspects refer to the natural fragility of the site, while the fourth relates to the influence of anthropogenic activities on stability of the environment, which greatly influences environmental fragility, as it can intensify existing fragilities.

The integration of these parameters allows for different degrees of fragility to be obtained in an area. Thus, Spörl and Ross (2004) consider that any changes in the natural environment, such as changes to the relief, soil, vegetation, climatic aspects and drainage system, affect the environment and the dynamics of the natural equilibrium.

The use of geographic information systems (GIS) in the assessment of environmental vulnerability has been widely applied in the field of information management, which makes it possible to merge multiple types of information in a study area into a single map, which can help in the management of resources and restore already degraded areas (Furlan et al. 2011).

In this context, multicriteria analysis presents itself as an important tool to analyze environmental fragility because this technique presents a structured method for data comparison and enables better decision-making processes (Cereda Junior and Röhm 2014, Martinelli et al. 2014). This analysis allows the gradual transitions between factors to be delimited in more detail and with better performance than Boolean analysis, which employs the simple crossing of maps that are classified into rigid intervals, resulting in imprecise information (Donha et al. 2006, Stolle et al. 2012).

Studies of changes in plant cover using remote sensing is also of great importance in the monitoring of natural resources, since it allows for the evaluation of the temporal and spatial variation of the vegetation cover over large areas (Bezerra et al. 2014, Gomes et al. 2009, Ohana-Levi et al. 2015).

In this type of monitoring, the normalized difference vegetation index (NDVI) is used to monitor the vegetative vigor of crops and forests and helps to identify the changes in the vegetative cover of the land, making it possible to plan actions to recover degraded areas (Lima et al. 2013).

In actuality, one of the major highlights of processing data using NDVI for vegetation cover change analysis is the Google Earth Engine (GEE) platform. Launched in 2013, this platform uses the JavaScript programming language for data processing in the cloud, minimizing processing and data storage times (Huntington et al. 2016, Warren et al. 2015). Huang et al. (2017) used Landsat images obtained from the GEE platform to map the dynamics of land use and land cover in Beijing, China, indicating that the GEE was an agile and powerful instrument for the mapping of land cover and provided high accuracy during the classification of maps.

In this context, the goal of this work was to analyze the environmental fragility of the Lapa Grande State Park (PELG), Minas Gerais, and its buffer zone (ZA), as well as to quantify the changes in the high vigor vegetation cover before and after the implementation of the park.

MATERIALS AND METHODS

STUDY AREA

The study area comprises the conservation unit (UC) of the Lapa Grande State Park (PELG) and its buffer zone (ZA). The PELG is located in the municipality of Montes Claros, which is approximately 5 km from the center of the city in the northern region of the State of Minas Gerais (Figure 1). The vegetation of the UC is mainly compost by *Cerrado* (central savannas) and forest fragments of *Mata Seca* (deciduous seasonal forest). The climate of the region is considered semiarid and exhibits an average annual precipitation of 1,074 mm (IEF 2014).

The PELG is an Integral Protection Conservation Unit that allows only the indirect use of natural resources, and it is important for the preservation of flora and fauna biodiversity and the protection and recovery of water, geological and archaeological resources. The buffer zone (ZA) constitutes a land strip around the conservation unit, delimiting the area of influence over the unit and acting to mitigate the negative impacts (Brasil 2000).

The city of Montes Claros has a population estimated of 402,027 inhabitants (IBGE 2017), and the study of the fragility of the area located around the park (buffer zone) is essential due to the urban occupation around the PELG because anthropogenic activities influence the quality of the natural resources.

Inadequate land use and removal of vegetation cover cause many changes to the hydrological cycle, such as increased surface runoff, erosive processes, and silting of rivers, besides damages to biodiversity (Cruz et al. 2017, Hamilton et al. 2013, Uddin et al. 2016). In this way, the present study considered a buffer zone of 3 km around the park boundary that was created by the CONAMA Resolution 428 on December 17th, 2010 (Brasil 2010).

The PELG was created by Decree No. 44204, dated January 01st, 2006, aiming mainly to conserve the complex caves and the local fauna and flora and protect some of the main sources that supply water to the urban area of Montes Claros (IEF 2014, Minas Gerais 2006). In Decree 46692 of December 29th, 2014, new areas were added to the park boundary (Minas Gerais 2014), doubling its area to a total of 15,177 hectares, besides its buffer zone with 21,578 hectares.

DATA SOURCE

For the mapping of the environmental fragility of the PELG and its ZA, four factors were evaluated: slope, pedology, geology and land use and land cover; these factors were also used by Pinese Júnior and Rodrigues (2012) and Terra et al. (2016).

The slope data were extracted from the digital elevation model (DEM) of the Shuttle Radar Topography Mission (SRTM) project (https://earthexplorer.usgs.gov/), with a spatial resolution of 30 meters (USGS 2017).

The soil data of the study area were extracted from the Minas Gerais Soils Map, which was created by the Universidade Federal de Viçosa, Fundação Centro Tecnológico de Minas Gerais, Universidade Federal de Lavras and Fundação Estadual do Meio Ambiente (UFV et al. 2010), at the scale of 1: 650,000.

The geology of the area was obtained from the Map of Geology of Minas Gerais, developed by the Company of Research and Mineral Resources and the Company of Economic Development of the State of Minas Gerais (CPRM and CODEMIG 2014), which was compiled for the study area by the East Minas Gerais Project at the scale of 1: 100,000.

Due to the difficulty of obtaining databases in Brazil, it was necessary to work with maps with different scales. The lack of detailed information on geology and, especially, pedology led to the necessity to work with maps with smaller scales. Scarcity of detailed information has been a typical

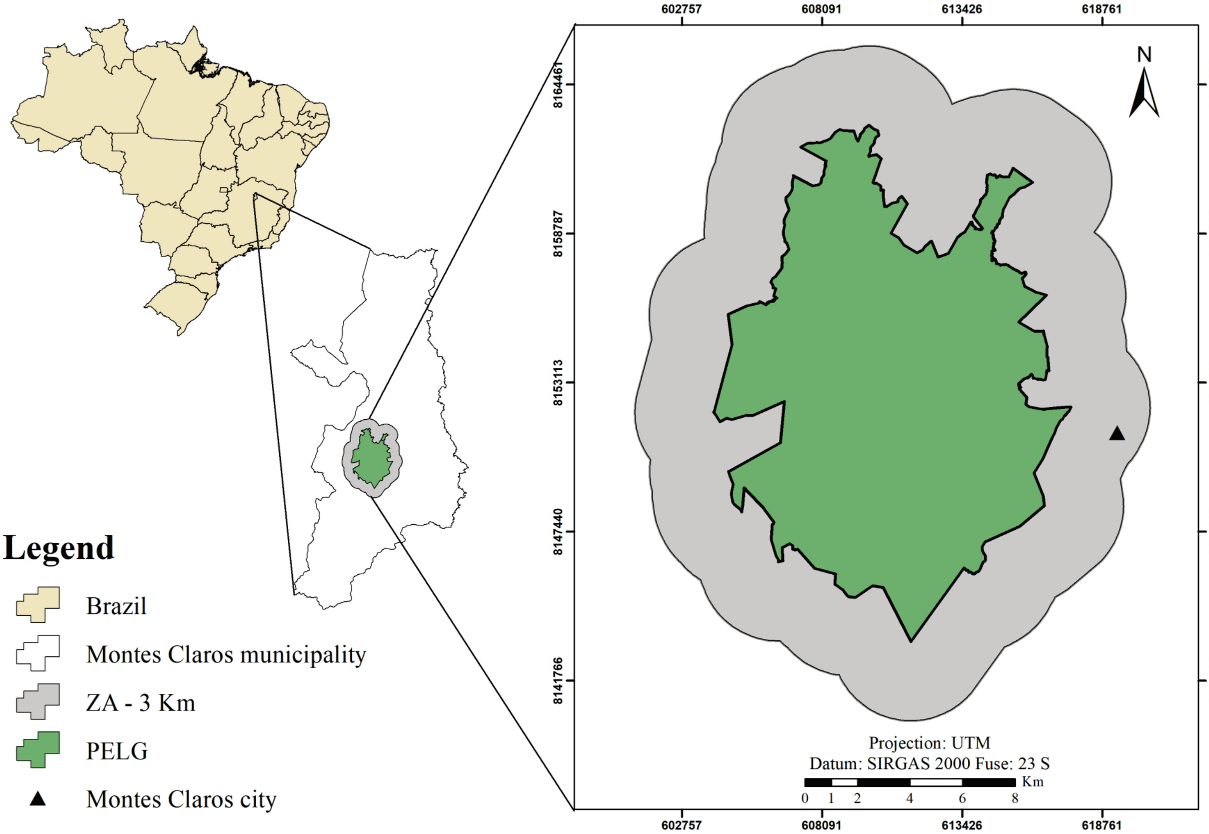

Figure 1 - Location of the Lapa Grande State Park (PELG) in the Montes Claros municipality, MG, Brazil, and its buffer zone (ZA).

problem of Brazil, due the territorial extension and lack of financial resources for research. In many regions, practically no research is conducted to obtain data on a detailed scale, hindering the supply of information to systems. The existence of a more detailed database would certainly enable an even more accurate analysis of the environmental fragility of the area under study.

The land use and land cover were elaborated from the classification of Landsat 5-TM (Thematic Mapper) images from the years of 1996 and 2006 and Landsat 8-OLI (Operational Land Imager) images for 2016 with spatial resolutions of 30 meters. The images were acquired from the GEE platform (https://earthengine.google.com/) (GEE 2017). The accuracy of the classification was evaluated using the kappa index (K), as proposed by Landis and Koch (1977).

As the slope, pedology and geology factors remained constant from 1996 to 2016 because they are permanent characteristics of the area, the differences in the data used for the fragility analysis in 1996, 2006 and 2016 will be related to the land use and land cover of the area, which was variable during the study period.

MULTICRITERIA ANALYSIS FOR MAPPING ENVIRONMENTAL FRAGILITY

The multicriteria analysis was applied to identify the areas with environmental fragility using the Idrisi Selva® 17 software. The classification of environmental fragility proposed by Ross (1994) was adopted, which considers weights for each class from 1 to 5, where the lowest fragility its attributed weight 1 and the highest fragility is attributed weight 5. For the software processing and to establish a comparison between the thematic maps, the scale of suitability was standardized from 0 to 255 according to the levels of (Lorentz et al. 2016) using the "*stretch*" function.

In this way, the classes of very high and high fragility presented values closer to 255, while the classes of lower fragility had suitability values closer to 0. Table I presents the classes for each factor analyzed and its respective fragility, according to the methods proposed by Ross (1994) and Crepani et al. (2001).

TABLE I
Environmental fragility degree associated with each class of the analyzed factors.

Factors	Class	Fragility
Slope	0-6%	Very low
	6-12%	Low
	12-20%	Medium
	20-30%	High
	>30%	Very high
Pedology	LVAd1	Very low
	LVAd21, LVAd22	Low
	NXe2, NXd1	Medium
	CXbd21	High
Geology	ENdl	Low
	K2u	Medium
	NP3bss, NP3bsh	High
	NP3blj	Very high
Land use and land cover	Forest and dense cerrado	Low
	Agricultural activities and shrub vegetation	Medium
	Degraded área and bare soils	High
	Urban area	Very high

Acronyms: LVA: *Latossolo Vermelho Amarelo* (Ferralsol); CXb: *Cambissolo háplico* (Cambisol); NX: *Nitossolo Háplico* (Nitisol); ENdl: detritus-lateritic cover with ferruginous concretions; K2u: Urucuia group, conglomerate sandstone; NP3bss: Bambuí group, Serra da Saudade formation; NP3bsh: Bambuí group, Serra de Santa Helena formation; NP3blj: Bambuí group, Lagoa do Jacaré formation. (Adapted of the Ross 1994, Crepani et al. 2001).

The slope limits used were determined based on the intervals presented in Ross (1994), which considers that plane areas are less susceptible to degradation, while areas with declivity above 30% have very high susceptible to degradation. For the hierarchical categorization of the pedology factor, the classification was adapted from Ross (1994), and the geology was adapted from Crepani et al. (2001). In addition, specialists were consulted to confirm the classification defined by the authors for soil types and geology in the study site, as showed in Table I.

For the pedology factor, acronyms are in accordance with the current Brazilian Soil Classification System (UFV et al. 2010). Soils are differentiated in terms of morphological, physical, chemical and mineralogical data, as well as environmental aspects, such as climate, vegetation and relief (EMBRAPA 2013, UFV et al. 2010). Thus, Ferralsols occur in flat sites, where LVAd1 presents more clayey texture and lower fragility and erosivity than LVAd21 and LVAd22 do, which have medium texture (Ross 1994). Eutrophic and dystrophic Nitisols, NXe2 and NXd1, respectively, occur from mild to undulating relief areas with low clay activity and moderate erosivity, whereas Cambisols, CXbd21, have lower profile depth and high natural fragility (EMBRAPA 2013). The pedology factor was classified until the high fragility class because there are not types of soil which determine very high fragility class for this factor in the study area, such as litolytics and quartz sands soils (Ross 1994).

Regarding the geology factor, the acronyms in the Table I represent the lithostratigraphic units present in the study area, allowing to evaluate the fragility of the main lithotypes that constitute them, determined by their capacity of resistance to weathering (Crepani et al. 2001). Thus, detritus-laterite coverings with ferruginous concretions (ENdl) are composed by deposits of different materials hardened by ferruginous accumulation, witch determine low erosivity and fragility. The Urucuia Group (K2u) is formed by conglomerate sandstone, this is a lithotype with less fragility than the formations composed by siltstones and claystones (NP3bsh and NP3bss). Those, on the other hand, determine less fragility than the carbonatic rocks (NP3blj), that have more vulnerability to the physical and chemical actions of weathering and for this reason, they are classified as the very high fragility (CPRM 2010, Crepani et al. 2001). The class of very low fragility was not identified in the study area, because in this class predominate the lithotypes: quartizites, granites, granodiorite and gneisses (Crepani et al. 2001).

The classification of land use and land cover was conducted according to the categories of fragility proposed by Ross (1994), which were a function of the degree of soil protection by the vegetation cover. The urban areas were considered to be very high fragility because they are not protected by vegetation cover (Cereda Junior and Röhm 2014) and forest areas were considered to have low fragility, mainly due to the interception of rainfall and the water retention capacity of the soil in this type of plant formation (Tonello et al. 2014). According to Pruski (2009), vegetation cover reduces surface sealing and soil disintegration, allowing for greater water infiltration. On the other hand, waterproofing urban areas significantly reduces water infiltration and increases surface runoff, potentiating the occurrence of flooding (Targa et al. 2012). The sites with degraded areas and bare soil have lower protection of the soil by vegetation, for this reason, it was classified as high fragility. Sites with agriculture and shrub vegetation were considered of medium fragility because this land use provides an intermediate protection of the soil compared to forest areas and bare soil.

To perform the multicriteria analysis, we first used the Analytic Hierarchy Process (AHP) tool, which allows us to create a hierarchy of existing relationships, allowing a broad view of the process by calculating the weights and indicating the level of consistency for the comparisons (Pinese Júnior and Rodrigues 2012). We also used a weighted linear combination (WLC) model multicriteria analysis to the support the decisions (Akgun and Türk 2010, Martinelli et al. 2014).

In the paired comparison matrix of the AHP method, the four factors were evaluated according to their importance, making it possible to obtain the calculated weights for each factor. The same level of relevance (1/3) was considered for the intrinsic factors of the area, such as the pedology, geology and slope. The land use and land cover were attributed a higher importance level (1), thus the weights were set to 0.1667 for the intrinsic factors and 0.500 for the land use and land cover, as also reached by Manfré et al. (2013). The inconsistency obtained for the proposed weights was 0.00, indicating excellent consistency between the factors and the weights adopted.

The WLC tool was used to associate the factors with the weights, perform the weighted combination for each pixel and then add the results to obtain the scenario of total compensation and average risk (Romano et al. 2015, Calijuri et al. 2007, Lorentz et al. 2016).

The analyses were done for the years of 1996, 2006 and 2016 to determine the environmental fragility before and after the implementation of the park. The environmental fragility maps obtained for each period that was analyzed were reclassified into five classes, aiming to quantify the areas contained in each level of fragility.

ANALYSIS OF VEGETATION COVER IN THE PELG

After analyzing the environmental fragility, we verified the contributions of the protection actions resulting from the implementation of the PELG in relation to the increase in dense vegetation cover (high vegetative vigor), since this allows for a greater protection of the soil in relation to a degraded area.

The vegetation cover changes were analyzed by calculating the NDVI for 1996, 2006 and 2016. The NDVI was obtained from Landsat images that were processed on the GEE platform. The Landsat images that were used have a spatial resolution of 30 meters and were radiometrically and atmospherically corrected. Images from the dry period (June to August) of each year were used to facilitate the distinction between dense cerrado and deciduous vegetation (less dense), as proposed by Espírito-Santo et al. (2016).

The NDVI reaches values from -1 to 1, and areas with denser vegetation tend to present values close to 1 because greener vegetation and vegetation with greater vigor show greater contrast in the visible region, specifically in the red and infrared (Zhong et al. 2017). The NDVI was calculated by Equation 1:

$$\mathrm{NDVI} = \frac{\mathrm{IVP} + \mathrm{Ver}}{\mathrm{IVP} - \mathrm{Ver}} \quad (1)$$

where *IVP* is the energy reflected in the near red region, and *Ver* is the energy reflected in the red region of the electromagnetic spectrum.

The NDVI values were evaluated for areas of dense vegetation that was composed of native forests and dense cerrado in the dry period, making it possible to reclassify the images and obtain maps of the vegetation with higher vigor for the evaluated years.

RESULTS AND DISCUSSION

Figure 2 shows the slope, pedology, geology and land use and land cover factors corresponding to the years 1996, 2006 and 2016 that were obtained for the study area and used in the multicriteria analysis.

In relation to the slope factor, steeper slopes, greater than 30%, were observed in the eastern and northeastern portion of the study area, determining the degree of very high fragility for regions related to this factor, as shown in Table I. In the pedology factor, a large area of Cambisol is observed in an extensive portion of the central region of the park, determining the very high fragility of this region in relation to the pedological factor. As for geology, there is predominance of Lagoa do Jacaré Formation (NPb3lj) covering the eastern center portion of the study site and determining the degree of very high fragility for the geological factor in this site.

Regarding land use and land cover, clear changes were observed during the time analyzed. In 1996, the central and eastern region of the park was heavily exploited. Agricultural activity in these sites led to the formation of degraded areas and bared soils, mainly in the park and in the eastern region. Urban sprawl was gradually occurring in the area. Therefore, areas with bared soil and in the urban area determined greater fragility degrees in this region. On the other hand, in the western portion of the buffer zone (ZA), there were larger areas of dense Cerrado and some areas for agriculture, which altogether determined less fragility for this region.

From 1996 to 2006, there was an expansion of agricultural activity in the eastern portion with an increase in cropped areas where the soil can remain bared due the different cropping and deforestation stages of Cerrado areas. In the western side, an opposite behavior is observed. In more degraded sites, land use was reduced, increasing dense vegetation. In 2016, after 10 years of creating the park, there was a significant increase of vegetation cover in the park perimeter and an increase in agricultural activity in the buffer zone with a reduction of degraded areas and exposed soils, mainly in the northeastern and southern portions of the park. The increase of vegetation cover with high vigor in the western region of ZA reflects the increase of areas with planted forest.

The kappa index (K) showed accuracies of 0.94, 0.77 and 0.79 for the years 1996, 2006 and 2016, respectively. According to Landis and Koch (1977), values of K between 0.61 and 0.8 indicate that the quality of the classification is considered very good, and values above 0.8 indicate that the classification presents an excellent representation of the actual use of the soil.

Table II shows the percentage of the area and the distribution of each attribute of the factor maps (Figure 2) present in the study area. This division is necessary to determine the influence of the attributes of each factor on the degree of fragility according to its representation. To facilitate the analysis and discussion of the results, the land use land cover of the total area was verified separately for PELG and ZA.

Table II shows that the majority of the study area is located in a class of slope that is considered to have low fragility (6-12%); 33.8% of the ZA area is located in this class, and 31.2% of the PELG is in this class. More of the areas with higher slopes are located within the perimeter of the PELG than within the ZA area (Figure 2).

In the pedology factor, the soil type *Cambissolo* Háplicos Tb Distróficos with mean texture (CXbd21), which is characterized by the low activity of clay (Cruz et al. 2016) predominates in 31.1% of the ZA area and 75.6% of the PELG area. It is also observed that the soil types *Nitossolo Háplico Distrófico* (NXd1) and *Nitossolo Háplico Eutrófico* (NXe2) predominate in 31.3% of the ZA area and 10.8% of the PELG. This soil associated with cambisols results in areas with higher degrees of fragility compared with areas with ferralsol formations, which are deeper and more weathered (Pereira et al. 2010, Manfré et al. 2013). Moreover, those types of soils are located in areas with higher slopes.

In the geology factor, the *Lagoa do Jacaré* Formation (NP3blj) predominates in 55.1% of the PELG area and 38.8% of the ZA area, and this formation is composed of limestone and dolomitic limestone. In addition, the Serra *da Saudade* Formation (NP3bss) and *Serra de Santa Helena* (NP3bsh) represent 41.3% of the ZA area and 32.8% of the PELG area, respectively; these formations are mainly composed by siltstones and belong to the same group (Iglesias and Uhlein 2009). Both lithotypes are composed of very fragile materials, as the rocks are formed by limestones and dolomites that are even more vulnerable to weathering than those formed by siltstones (Crepani et al. 2001). The geology factor presents great importance in soil erosivity and the environmental fragility of the area because it is associated with the source material (Gonçalves et al. 2011).

The evaluation of the change in land use and land cover in the ZA revealed that there was a progressive reduction of forest and dense cerrado areas of approximately 7.6% from 1996 to 2016; the areas of agricultural activities and shrub vegetation increased by 14.6%; the degraded areas and areas with bare soil decreased by 10.8%, and the urban area of Montes Claros city increased by 3.9% during this same period. With the implementation of the PELG, forest and dense cerrado areas increased by 17.5% from 2006 to 2016 in the park, with a 6.3% decrease in the area of agricultural activities and shrub vegetation, and an 11.2% decrease in the degraded areas and soil exposed area in the same period.

Therefore, there are large areas located in the central region of the park with greater fragility related to intrinsic factors, due to characteristics of the attributes of each factor. For example, in the pedology factor, Cambisols are more susceptible to degradation, determining greater vulnerability of sites where all the natural factors have high fragility in the same area, emphasizing the importance of increasing areas with vegetation cover that provide greater soil protection.

TABLE II
Percentage of the area for each attribute of the factors used in the fragility analysis in the perimeter of the ZA and PELG.

Slope	Area in the ZA (%)	Area in the PELG (%)
0-6%	29.3	19.1
6-12%	33.8	31.2
12-20%	20.5	25.5
20-30%	9.6	13.3
>30%	6.8	11.0
Pedology	Area in the ZA (%)	Area in the PELG (%)
LVAd1	15.6	12.6
LVAd21, LVAd22	22.0	1.0
NXe2 and NXd1	31.3	10.8
CXbd21	31.1	75.6
Geology	Area in the ZA (%)	Area in the PELG (%)
ENdl	19.4	12.1
K2u	0.6	0.0
NP3bss, NP3bsh	41.3	32.8
NP3blj	38.8	55.1

Land use and land cover	Area in the ZA (%)			Area in the PELG (%)		
	1996	2006	2016	1996	2006	2016
Forest and dense cerrado	44.4	39.6	36.8	48.0	50.7	68.2
Agricultural activities and shrub vegetation	17.3	22.9	31.9	12.9	17.7	11.4
Degraded area and bare soils	33.3	30.6	22.5	39.1	31.6	20.4
Urban area	5.0	7.0	8.9	0.0	0.0	0.0

ENVIRONMENTAL FRAGILITY

Figure 3 shows the maps obtained from the analysis of the environmental fragility of the study area for the years 1996, 2006 and 2016. The results indicate that the highest degrees of fragility in 1996 are generally concentrated in the center-east and northeast regions of the study area and the urban area located in the east of the park and the buffer zone (Figure 3a). From 2006 to 2016 (Figure 3b, c), it is clear that the environmental fragility is minimized within the limits of the conservation unit, due to the improvement of land use and land cover, with the highest fragilities prevailing in the area Montes Claros city.

The higher fragility in the central-east and northeast portions of the PELG in 1996 is mainly due to the high potential or natural fragility of the site, which increases the environmental fragility when combined with inadequate land use and land cover. In other words, the high susceptibility of the factors that do not present significant modifications over time, such as slope, pedology and geology, already predispose this region to high fragility, which increased the levels of fragility at the sites associated with degraded areas and exposed soil.

In this region there are areas with higher slopes, according to Cogo et al. (2003) the runoff erosion capacity increased as the slope also increased, this is due to higher water velocity. Thus,

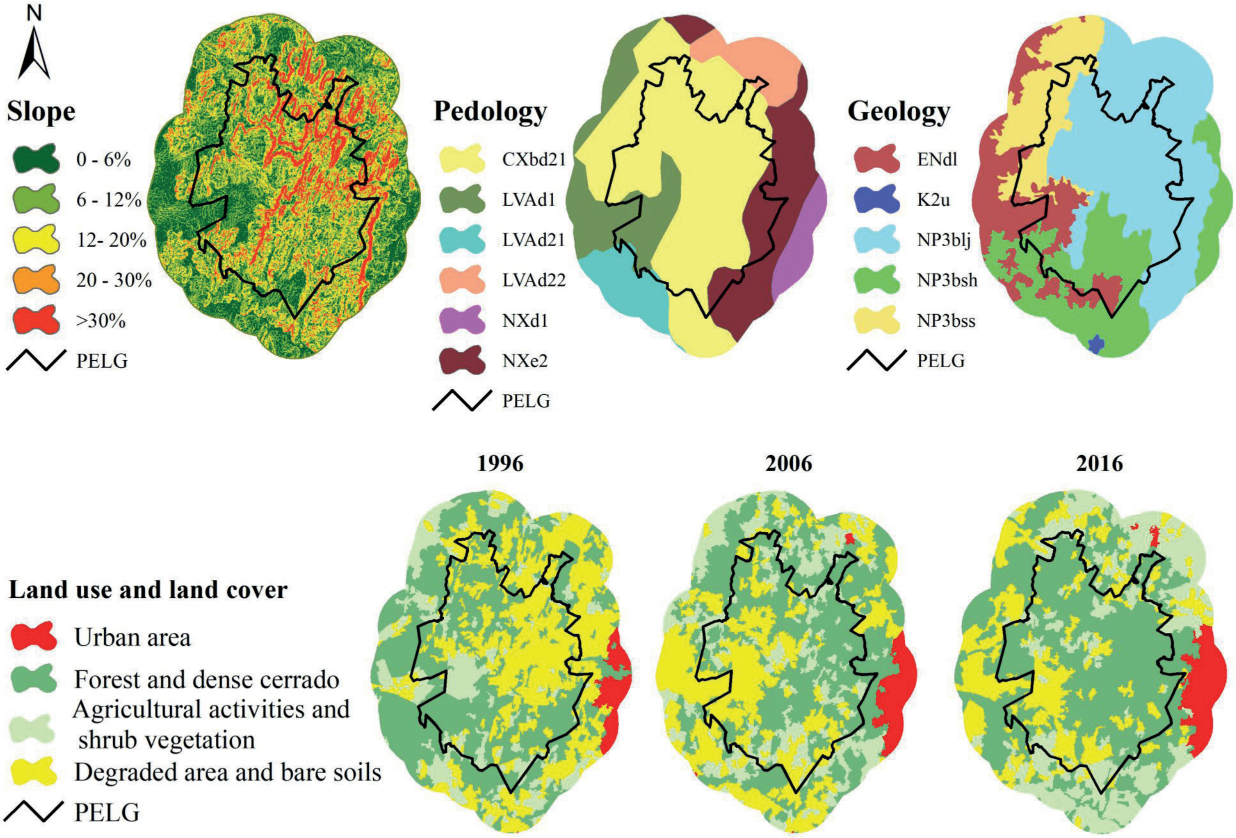

Figure 2 - Factors used in the zoning of environmental fragility of the PELG for the years of study.

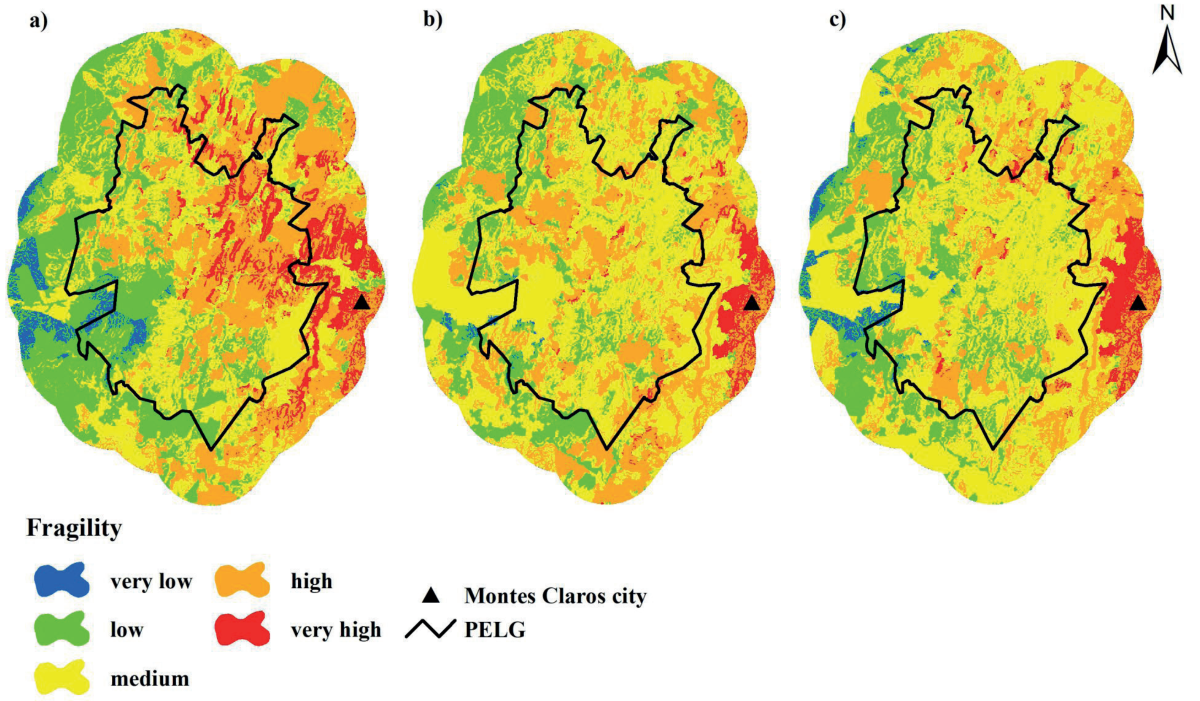

Figure 3 - Environmental fragility maps of ZA and PELG for the years 1996 (**a**), 2006 (**b**) and 2016 (**c**).

areas with higher slopes are more likely to have greater environmental fragility. In addition, it was verified that the areas with high slopes are mainly cambisol and nitisol, which are more susceptible to erosive processes. The geology factor also had a higher influence on the results that were obtained, because there is a predominance of siltstone and limestone in the central-east and northeast regions of the area, which, according to Crepani et al. (2001), determines higher values of environmental vulnerability.

From 2006 to 2016, there was a reduction in the degrees of fragility in the western region of the buffer zone mainly because the implantation of planted forest areas. On the other hand, in the eastern region there were changes in the classes of land use including the bared soil and degraded area for the classes of agriculture and shrub vegetation, which do not provide great improvements in relation to the degree of environmental fragility. There is also an expansion of the urban area during the analysis period, which resulted in an increase in the degree of very high fragility around the of Montes Claros city.

The quantitative improvement of the fragility degrees with the implementation of the park was also verified. The percentage of area in each fragility class for the analyzed periods can be observed in Figure 4.

By quantifying the percentage of the area in each fragility class in the PELG (Figure 4a), it was observed crescent percentages of areas classified as medium class of fragility. In 1996 this class totaled 36.2% of the evaluated area, while in 2006 and 2016 the values for this class were 56.9% and 62.9%, respectively. After 2006, with the implementation of the park, there were an increase in the low fragility and reduction in the high fragility areas. This behavior was probably associated to the increase of the dense vegetation cover after the protection of the area with park's creation, which resulted an improvement in the degrees of environmental fragility.

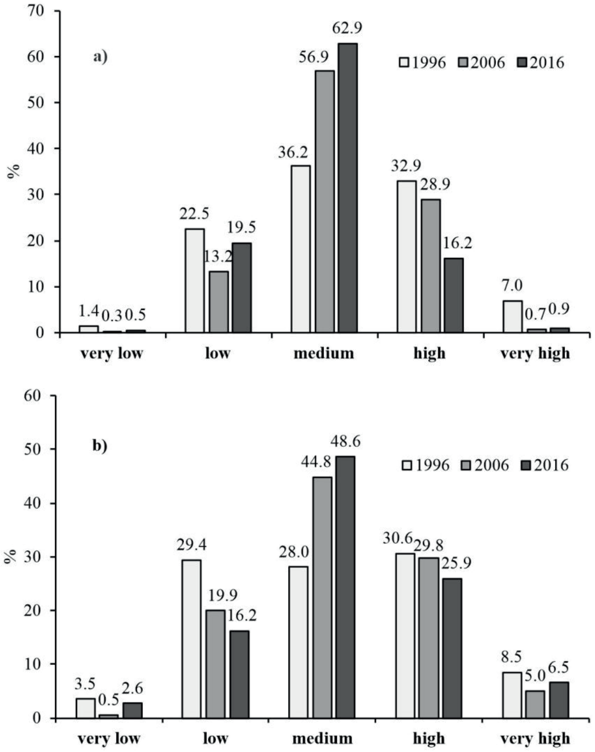

Figure 4 - Percentage of the area distributed in the environmental fragility classes for the years of study in the PELG (**a**) and ZA (**b**).

It should be emphasized that the potential fragility in the park area tends to be naturally higher, since the natural and intrinsic factors of the site, such as the geology, pedology and slope, are more fragile than in the ZA and, when combined, these factors potentially result in environmental vulnerability. Thus, the importance of implementing a conservation unit for the purposes of improving the land use and land cover and mitigating the environmental fragility of the PELG is evidenced.

In the ZA, the sites with the high fragility and very high fragility classes remained practically stable (Figure 4b), during the analysis period. It was because, unlike the area of the park, the anthropogenic activities in the ZA are less restricted, which did not result in greater improvements in the environmental fragility in this area with the park implementation. Furthermore, it was verified a reduction of the sites with low fragility and an increased in the sites with medium fragility, that is, a relative worsening of the fragility degrees between 1996 and 2016.

CHANGE IN THE VEGETATION COVER OF THE PELG

The NDVI values during the dry period in the study area were analyzed, and it can be observed that the minimum and maximum NDVI values increased progressively during the analysis period. The minimum values of -0.49, -0.47 and 0.11 and the maximum values of 0.75, 0.86, and 0.9 were identified for the years 1996, 2006 and 2016, respectively. On the other hand, the average values increased from 0.38 in 1996, and the average was similar in 2006 (0.57) and 2016 (0.56).

The negative minimum NDVI values refer to watercourses. It is assumed that in 1996 and 2006, the vegetation could not cover the watercourses, which could, therefore, be identified by the negative NDVI values. However, in 2016, there was an increase in the denser vegetation area, and this dense vegetation may have covered the watercourse areas. For this reason, it was not possible to identify negative values in 2016.

It should be emphasized that vegetative vigor is influenced by the rainfall patterns of each year. According to Becerra et al. (2009), rainfall is one of the main factors that influence the occurrence and distribution of cerrado vegetation, and a seasonal pattern occurs, in which high rainfall values correspond to higher NDVI values, which decrease in the dry period.

The rainfall levels during the years considered in this study were analyzed, and it is verified that the rainfall indices in 2006 were much higher than those in the years of 1996 and 2016. During the rainy season (October to March), before the dry period was considered for each year, the registered pluviometric indexes were 850.5 mm in 1996 and 694.6 mm in 2016, while in the same period in 2006 the rainfall was 1075.3 mm. Even in the dry period (April to September), the precipitation registered in 2006 was still higher than in 1996 and 2016, and these values were 277.0, 77.3 and 26.3 mm, respectively. These data were obtained from station 83437 of the National Meteorological Institute (INMET 2017), located in Montes Claros.

Thus, it is verified that there was an improvement in the mean NDVI value during the dry periods of 1996 to 2016, noting that the value obtained in 2006 refers to atypical rainfall conditions.

In relation to the percentage of vegetation coverage obtained by the NDVI (Figure 5), 18.7% of the PELG area in 1996 was occupied by vegetation that had higher vegetative vigor, which was mainly composed by forests and dense cerrado; this value was 20.1% in 2006 and 40.9% in 2016. The vegetative gain from 1996 to 2006 was approximately 1.4%, while after the implementation of the PELG, the increase was 20.7% from 2006 to 2016. It is also verified that despite the fact that the highest average NDVI value of the dry period was obtained in 2006, the area occupied by the most vigorous vegetation was smaller in 2006 than in 2016.

In 1996, the PELG had not yet been created, therefore there were several rural properties on the site of the park that contributed to the reduction of areas with vegetation cover and favored the formation of pastures. The lower vegetative vigor in this period may also be related to several other factors, such as the occurrence of cerrado and dry forest areas, irregular rainfall distribution, elevated temperatures and anthropogenic activities, such as fires in agricultural areas (Assis 2014).

The increase in the dense vegetation from 2006 to 2016 is therefore, mainly due to the implementation of the PELG in January 2006 and the consequent expropriation of several properties,

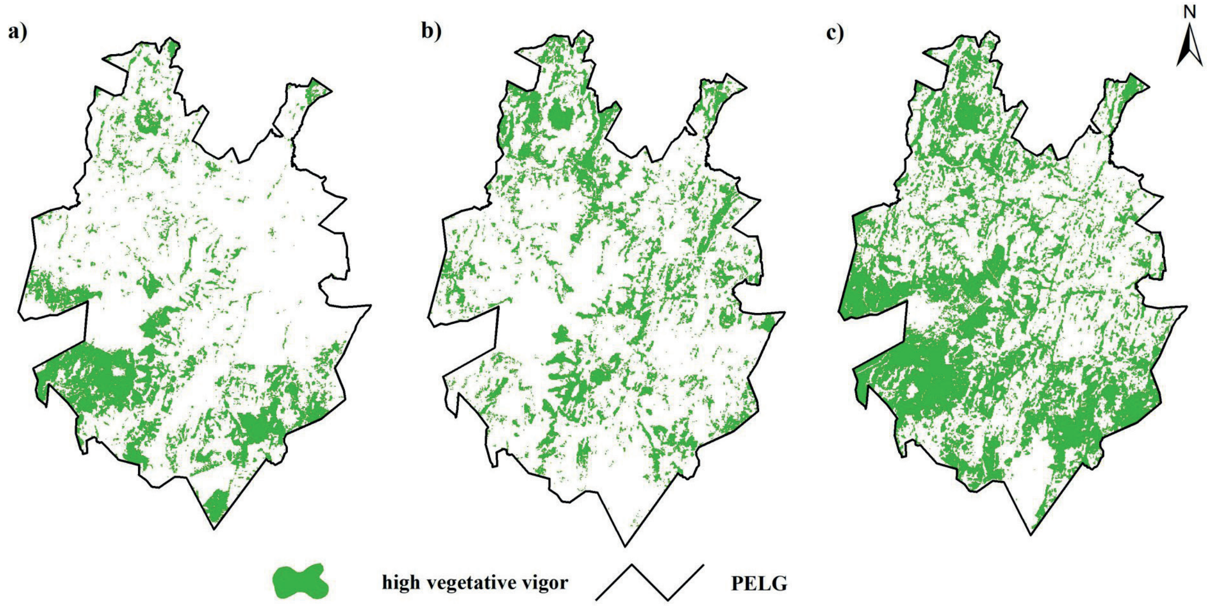

Figure 5 - Evaluation of the vegetation cover change obtained by NDVI for the dry periods of 1996 (**a**), 2006 (**b**) and 2016 (**c**).

which favored the conservation of the area. As evaluated in the analysis of land use and land cover, the increase of this type of vegetation occurred only in the area of the park, since the reduction of this type of vegetative formation was verified in the ZA. Thus, in this period of 20 years, the approximately 22% gain in high vigor plant cover was relevant and certainly contributed significantly to the conservation of soil and water in the region.

CONCLUSION

Based on the results, we conclude that:

- Central, eastern and northeastern regions of the Lapa Grande State Park presented higher environmental fragility in 1996, because inadequate use of land has aggravated this problem, in addition to the natural susceptibility of the intrinsic factors of the area;

- There was significant reduction of the environmental fragility degrees between 2006 and 2016 due to an increase 17.5% of forest areas and dense Cerrado after the creation of the conservation unit, which mitigated the natural fragility of the area;

- The percentages of the areas in the high and very high fragility classes reduced from 1996 to 2016, and this reduction was more significant in the park area than in the buffer zone, showing the need for more intense inspection of anthropogenic activities around the park;

- The gain of vegetation cover with higher vegetative vigor after the implementation of the PELG from 2006 to 2016 was 20.7%, significantly higher than that from 1996 to 2006, that was 1.4%, confirming the importance of the creation of the conservation unit to the preservation of the environment;

- Although the data available present less detailed scales, the results obtained with this study were effective to understand the land use dynamics and identify the environmentally fragility areas, being a valuable method to evaluate the evolution of the environment condition due to factors and human activities pressures;

- It was verified that environmental fragility analysis is an important tool for the decision makers by environmental managers since it can help preserve the less vulnerable places and contribute to the implementation of measures to adapt the areas with inherent risks with regard to soil and water degradation.

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AUTHOR CONTRIBUTIONS

JAC: main author, responsible for obtaining and processing the database, results analysis, manuscript writing, elaboration of tables and figures, and perform the reviews requested by the reviewers.

URVA: responsible for helping in the processing and analysis of the data, preparation of the manuscript for submission, adequacy of figures and tables, and translation of the manuscript into English.

DDS: responsible for the revision of the manuscript, orientation in the development of the work, helping in the interpretation of the results obtained, and suggested for perform new analyzes to improve the quality of the manuscript.

MLC: responsible for helping in the processing of the multicriteria analysis used in this work, performed revisions and suggestions for the preparation of the manuscript.

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