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Landscape quality and soil loss across the simulation of environmental scenarios in the Brazilian savannah

Gabriella Santos Arruda de Lima[1]
Nilson Clementino Ferreira[2]
Manuel Eduardo Ferreira[3]

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Abstract
The present study applied spatial metrics to assess the current fragmentation of the landscape in the Metropolitan Region of Goiânia (RMG), in order to establish priority areas for forest maintenance and restoration. For this, three scenarios were simulated, the first being the current condition, the second considering the forest restoration in Areas of Permanent Protection (APP) along the water courses, while in the third scenario the reforestation occurred in the regions of high and very high environmental vulnerability in the study area. This research also aimed to evaluate the loss of soil by laminar erosion applied to the three proposed scenarios for the region. This study showed that, in the RMG, according to the current configuration of the landscape, there has been high fragmentation of the remnant vegetation, where the reforestation is highly recommended. The spatialization of these results and the indication of areas for reforestation and conservation act as a guideline to public policies and in collective decision-making involving all the municipalities of the RMG.

[1] Universidade Federal de Goiás. Laboratório de Processamento de Imagens e Geoprocessamento. Goiânia, GO, Brasil. gabibela_l@hotmail.com
[2] Universidade Federal de Goiás. Escola de Engenharia Civil e Ambiental - EECA. Goiânia, GO, Brasil. nclferreira@gmail.com
[3] Universidade Federal de Goiás. Laboratório de Processamento de Imagens e Geoprocessamento. Goiânia, GO, Brasil. manuel@ufg.br

INTRODUCTION

The expansion of the agricultural frontier and urbanization are worldwide important factors in environmental degradation. One of the consequences of the urbanization processis the fragmentation of the native plant cover, derived from the growth and modificationof land use over preserved areas, causing the so-called “edge effect” and the inevitable weakening of a biome. As the transformations progress, the degree of isolation of the vegetation remains also increases (FORMAN; GODRON, 1986; TURNER, 1996; RODRIGUES, 1998; TILMAN, 1999). Among the factors responsible for the fragmentation of habitats are natural causes, such as fluctuations in hydrographic courses, flooding, as well as causes associated with the growth of human activities.

The greatest causes of fragmentation in the Cerrado biome are deforestation and the fire, which put great pressure on the remaining areas and on the wildlife. Even with the efforts of the state and federal environmental agencies, every year disasters still occur with high frequency (CAMARGO; SCHIMIDT, 2009; BRITO, 2012). Therefore, the preservation and connection of forest fragments is required to preserve the proper ecological functions, enabling the flow of species.

In this study, the present theme of fragmentation in the Cerrado issue was addressed in the Metropolitan Region of Goiânia (RMG), an area of 7,315 km², located in the center of the Cerrado biome, in an area greatly affected by the expansion of the agricultural border (intensified in this region between the 1970s and 1990), with high rates of deforestation and changes in land use patterns. The small spatial scope also enabled greater control of the methodology, using updated databases in a larger cartographic scale. The RMG still has the aggravating factor of being a high concentration urban area, which implies more drastic changes in the landscape, such as industrial pollution, deposition of waste in rivers, PPA urbanization, among others.

Thus, the objective of this work was to measure and evaluate the current fragmentation of the remaining vegetation in the Metropolitan Region of Goiânia, using as the landscape metrics, aiming to establish priority areas for forest maintenance and restoration. To this end, it is proposed to generate three scenarios with different levels of forest cover and impacts on soil loss due to laminar erosion. The first scenario is the current situation, the second is the full compliance with the forestry legislation regarding Permanent Protection Areas (APP), along the water courses; and the third scenario is reforestation only in regions with high and very high environmental vulnerability.

MATERIALS AND METHODS

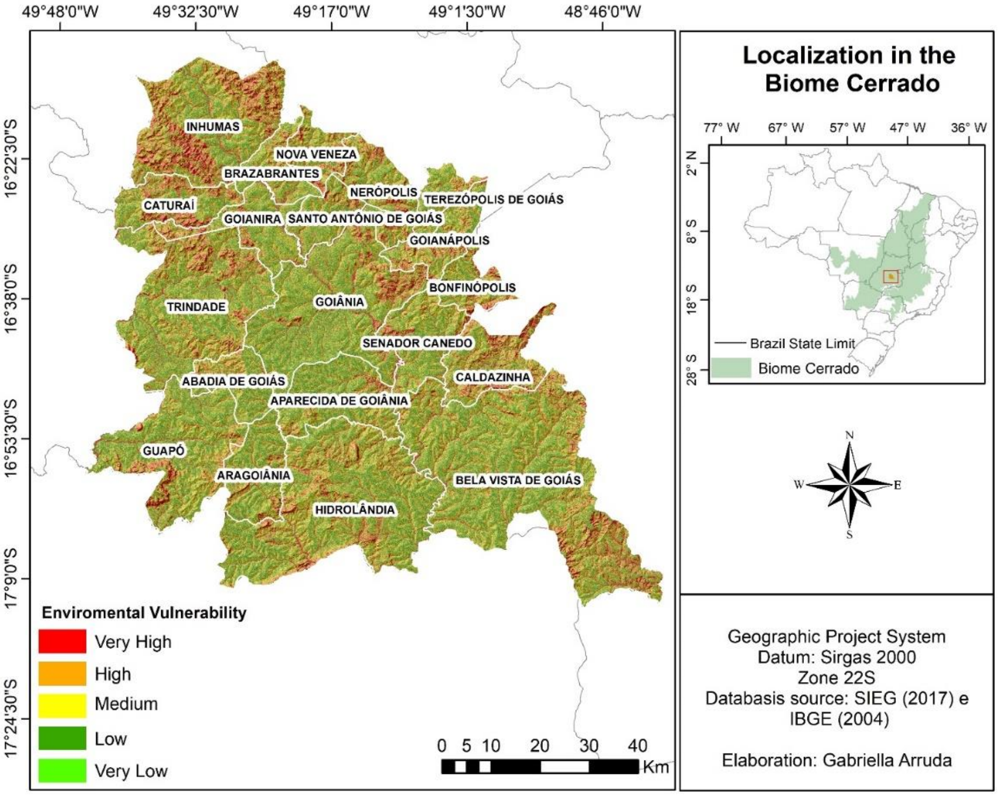
Characterization of the study area

Located in the central-south portion of the State of Goiás (Figure 1), between 16° 08’ and 17° 12’ S and 49° 44’ and 48° 48’ W, the Metropolitan Region of Goiânia was created in 1999, initially comprising 11 municipalities. In 2010 and 2011, the RMG assumed its current format, with 20 municipalities, occupying a territory of 7,315 km².

Under the Integrated Development Project of the Goiânia Metropolitan Region (PDIRMG, 2017), the environmental vulnerability was mapped, which in turn employed erosion potential maps, topographic moisture index, water table depth, and relief slope. The final vulnerability map was categorized into five classes: Very high vulnerability, high vulnerability, medium vulnerability, low vulnerability, and very low vulnerability (Figure 1).

In this region, the following Conservation Units (UC) were created as Units of Integral Protection to preserve biodiversity: , the João Leite State Park (PEJol), the Altamiro de Moura Pacheco State Park (PEAMP), and the Telma Ortegal State Park (PETO); and as Sustainable use units, the João Leite Environmental Protection Area (APA – João Leite) and the Serra das Areias Environmental Protection Area (APA – Serra das Areias). Together, these units total 97.653 ha, or 13% of the total area of the RMG.

Figure 1 - Location of the Metropolitan Region of Goiânia and its member municipalities, regarding their level of environmental vulnerability.



Source: PDIRMG (2017).Org.: the authors.

Methodological procedures

In order to perform the analysis of landscape fragmentation, establishing priority areas for forest restoration, as well as measuring the loss of soil after forest restoration scenarios, the following steps were defined:

(i) fieldworks to validate the land-use and land-cover map;

(ii) delimitation of sites for reforestation in Permanent Protection Areas (PPA);

(iii) delimitation of areas for reforestation, using as background the mapping of environmental vulnerability;

iv) performing of two simulated scenarios, later compared with the current scenario of remaining vegetation (reference): a) PPA scenario: Remaining vegetation + recovered PPA; b) reforestation scenario: Remaining vegetation + reforestation;

v) calculation of landscape metrics for the current scenario (reference) and simulated ones using the Patch Analyst® 5.2 for the software ArcGIS®, developed by Rempel et al. (2012).

(vi) calculation of soil loss by laminar erosion between the current scenario and simulated scenarios (i.e., considering the recovered PPA, and reforestations in vulnerable areas).

In the fieldwork stage (October 2017), randomly distributed points were visited within a 40-meter radius of the RMG highways, with the geographic positioning of these points confirmed through the use of a GPS absolute navigation-type (i.e., without post-processed correction), coupled to the Avenza Maps® application. The collected points were plotted on the land-use and land-cover map elaborated by LIMA et al. (2017), to assess the current forest fragmentation.

In order to apply the reforestation scenarios to this research, it was necessary to discuss the current scenario of conservation in the study area. For this purpose, a validation of the land-use and land-cover map was initially performed according to the areas visited in the fieldwork, resulting in confirmation of the classification accuracy.

For example, in the areas where the soil was exposed, the classification was maintained as initially indicated, and this procedure was adopted due to the annual variation due to harvests and burning, which alter the visual aspect and the spectral response of the target, but in general they do not change the land use.

The land-use and land-cover map of the Metropolitan Region of Goiânia was used to quantify the various types of use and to apply the landscape metrics to the remaining vegetation class. According to Lima et al. (2017), this map was drawn up from Landsat 8/OLI sensor images for the years 2015 and 2016. The classes considered were agriculture, urban area, remaining vegetation, water bodies, and pasture.

In this work, thirtymeters (30 m) of PPA was considered for water courses with less than 10 meters wide, and 50 meters for waterways between 10 and 50 meters wide, including those of natural, perennial, or intermittent origin, from the edge of the channel to the regular bed. The areas around the springs and fountainheads of the perennial waters were also mapped, regardless of their topographical situation, within 50 meters, according to the Brazilian Forest Code (BRASIL, 2012).

For this purpose, the local linear hydrography was obtained from the cartographic base produced by the Brazilian Institute of Geography and Statistics (IBGE), in the 1:100,000 scale, and made available by the Goiás State Geoinformation System (SIEG) platform. This database was used to map areas of influence (buffers), in each margin of the main water courses and around the springs, simulating the legal adequacy of the PPA.

Regions for reforestation in areas of high and very high environmental vulnerability were defined taking into account the abiotic aspects, erosive susceptibility, topographic moisture index, water table depth, and relief slope were also selected.

The mapping of environmental vulnerability produced the following cartographic products: Erosive susceptibility map, which was made using the Universal Soil Loss Equation (USLE); altimetry, produced from the integration between the SRTM data (Shuttle Radar Topography Mission) and aerophotogrametric data. Then the data went through interpolation by the Australian National University Digital Elevation Model (ANUDEM) method in order to obtain a Digital Model of Hydrographic consistent Elevation (MDEHC) for the RMG, with 10-meter spatial detailing. The resulting of the MDEHC was used to produce the slope map (in degrees).

The calculation of the topographic humidity index was derived from the algebra map between the flow accumulation and the slope map, and these two mappings were obtained from the altimetric map (Digital Terrain Model - DTM). The water table depth and mapping were obtained from the static level, observed in deep tubular wells, located in the RMG. These data were made available through the SIEG platform. These products were integrated and categorized, resulting in the environmental vulnerability map, classified according to Ferreira (2014) as follows: Very high vulnerability, High vulnerability, Medium vulnerability, Low vulnerability, and Very low vulnerability.

After the landscape analysis (spatial metrics), PPA mapping and the design of priority areas for forest restoration, the following scenarios were analyzed: Current remnant vegetation (reference); Remaining vegetation + recovered PPA; and Remaining vegetation + reforestation. These scenarios were developed to measure the area that needed to be reforested, partially complying with the legislation that deals with the PPAs, making a comparison with the current forest fragmentation, and evaluating the potential benefit of reforestation in the soil loss due to laminar erosion.

The "current" soil loss scenario was obtained from erosive susceptibility mapping elaborated by Lima et al. (2018). To compare soil losses, the PPA scenario + reforestation was simulated, from which a new erosive susceptibility map was developed. These maps were produced using the USLE. This equation is composed by the following factors: erosivity, erodibility, topography, land-use and land-cover map, and management practices. Based on these factors, a map algebra was made in a Geographical Information System (GIS), resulting in a spatialized erosive susceptibility map.

The mapping of the erosive susceptibility of the simulated scenario (PPA reforestation) used the same factors (erosivity, erodibility, topography) and the same methodology. However, the land-use and land-cover factor was modified, adding the simulated areas in the forest restoration.

To evaluate the fragmentation in the current and also in the other two hypothetical scenarios (PPA and reforestation), the landscape metrics were defined. According to the Patch Analyst, the metric used to determine the total sum of the remaining fragments was the class area (CA). For density analysis and fragment size, metrics of mean size of the fragments (MSP) and the number of fragments (NUMP) were used. The shape metric was generated with the mean shape index (MSI), resulting in the assessment of the proximity among the fragments, from the mean distance of the nearest neighbor (MNN).

RESULTS AND DISCUSSION

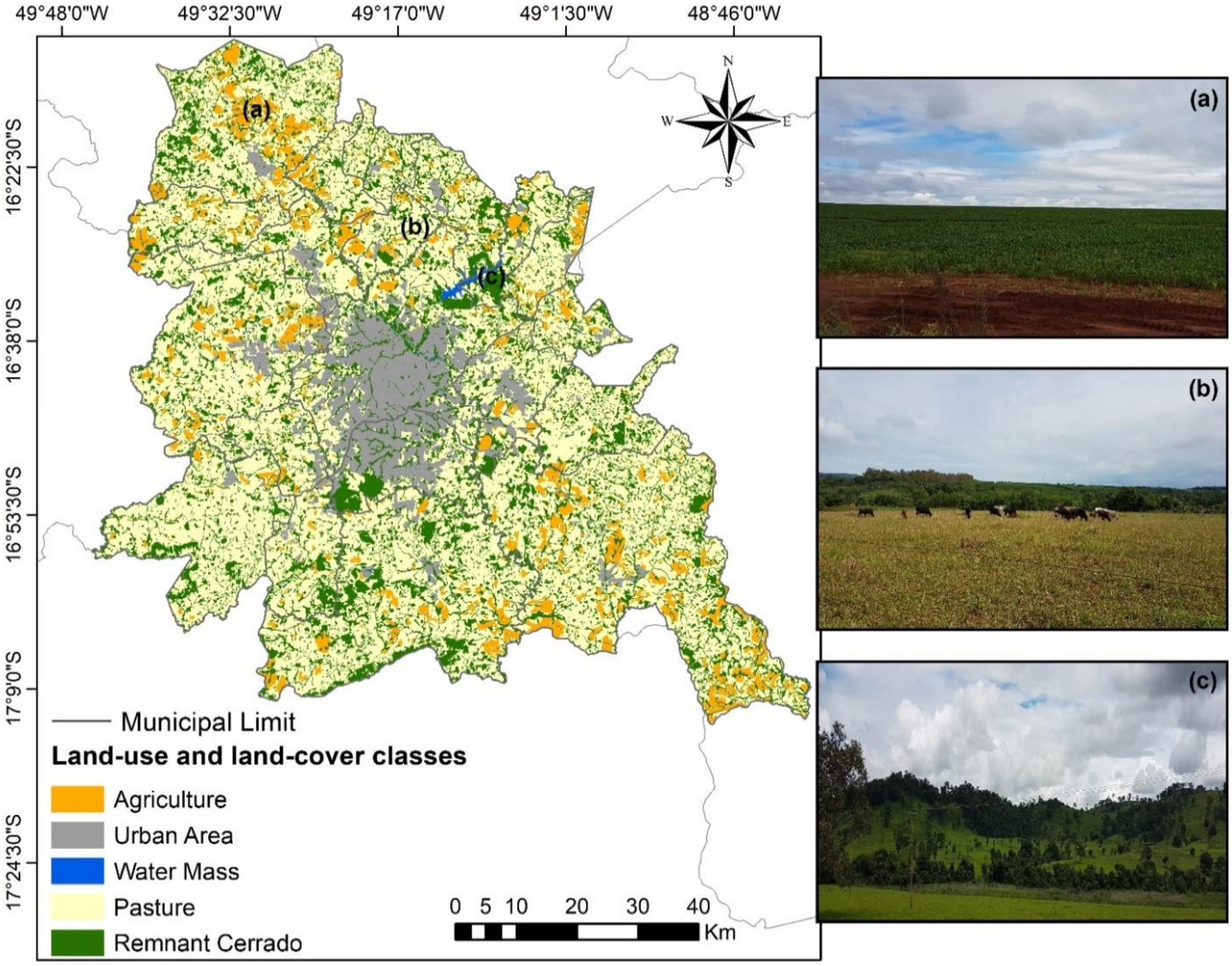
Analysis of land-use and land-cover map

Figure 2 shows pictures of the three visited locationswith their land use in the map.

According to this map (LIMA et al., 2017), the predominant matrix in the landscape is pasture, present in 58.21% of the area, followed by a Cerrado remnant, with 23.28% agriculture, and 8.32% urban area (currently in intensive expansion) with 9.15% of the region.

The vegetation remnants are under strong anthropic pressure, mainly due to urban expansion and agropastoral activities. It was possible to observe a high urbanization, including the trend of reduction in the rural population in this region, with the rate of urbanization reaching 98% between the 1990s and the 2000s, (IBGE, 2010).

Figure 2 - Land-use and land-cover map with the respective photographic records during the fieldwork. Agriculture (a); Pasture (b); and Cerrado remnant (c).



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Analysis of the current scenario using landscape metrics:

Concerning the landscape metric analysis, our study has indicated that this region has 6,139 forest fragments (NUMP), indicating a high degree of rupture of the landscape unit. These fragments are distributed in 173,447 hectares of remnants, representing 23.28% of the remaining vegetation of the total RMG landscape in its 20 municipalities. According to Metzger (1998), restoration of connectivity should be highly considered in regions where the fragmentation process of the original coverage is intense and has exceeded the 30% forest cover threshold.

The size of the fragments varied between 0.3 and 3,136.05 ha, with a mean size of the spots (MSP) of 28.25 ha. Forty nine per cent of the fragments have an area of less than 10 ha, indicating the predominance of small fragments. According to Pirovani et al. (2014), the metrics related to fragment area are one of the main factors for assessing its conservation level. The small areas support fewer animal species. The greater the number of fragments, the greater the reduction in habitat diversity and, consequently, in the number of habitats (CULLEN et al., 2005; ALBERGARIA, 2006).

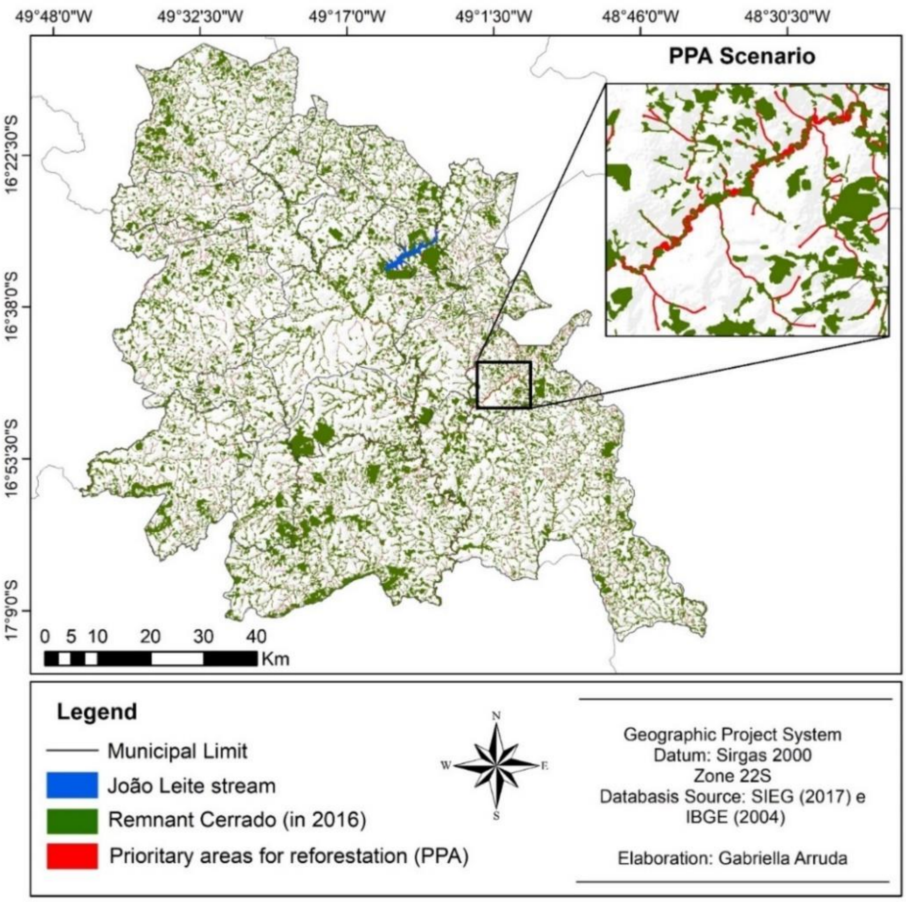
The mean shape index (MSI), with a value of 2.11, indicating low circularity of the fragments In this index, the values closer to 1 represent the most circular or ideal forms of the landscape, due to a lower influence of the edge effect on the ecosystem (LANG; BLASCHKE, 2009).

The mean MNN among the fragments was 442.15 meters, based on the distance from one edge to the other. This metric indicates that the RMG fragments are currently distant from each other, revealing the low level of connectivity among the vegetation remnants. The degree of isolation of the landscape interferes with the gene flow among the forest spots, therefore potentiating the effects of fragmentation on the habitats (VIANA, 1998; ALANDI et al., 2009).

Analysis of the APP scenario using landscape metrics:

Concerning the PPA analysis, the regions to be reforested, representing the environmental liability of the PPA, corresponded to 15,011.46 ha, which represented 33% of the total marginal zone to the water bodies. It appears that even with the legislation limiting its use or deforestation, the vegetation of the APP has already been intensely modified along watercourses of the entire RMG.. In the PPA scenario simulation, the current 29.966,15 ha of plant cover present in the PPA would reach 44.977,62 ha of forest cover, according to Figure 3.

Figure 3 - Simulation of the APP scenario with indication of locations without vegetation cover, which should be recovered.



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With the simulation of environmental adequacy (according to the Forest Code), the forest increase in the PPA scenario would represent44% reduction in the number of fragments, since the new configuration would be 3,446 spots (NUMP) in an area (CA) of 189,697.76 ha of native vegetation. This reduction of fragments occurs due to the integration of the spots. The largest fragment in the landscape (Remaining + reforested PPA) it would have119,143.93 ha, which corresponds to 63% of the interconnected area, favoring the connection of one or more contiguous areas, that is, the formation of a large forest corridor.

In this scenario, the average size (MPS) of the fragments would increase to 55.05 ha, while the average form index (MSI) would change to 1.73, which represents an environmental improvement, since a value close to 1 represents fragments with a more regular format, close to the shape of a circle, and less susceptible to the edge effect, compared to the current scenario.

The MNN presented 328.38 meters, which revealed the greater proximity between the fragments; this behavior is expected since the fragments are more connected, which results in a reduction in isolation. According to MacArthur & Wilson's Island Biogeography Theory (1967), the discontinuity of the forest or the distance between the fragments makes it difficult impairs the animal movement and the genetic flow, that is, the environmental richness decreases with the increase of isolation. Therefore, it reduces the probability of a species reaching another fragment (PRIMACK; RODRIGUES, 2001; MORIN, 2005).

Currently, the high anthropic nature of these areas and the fragmentation of the remnants were observed, with more than 33% of the PPA converted to several other uses in the RMG. Martins (2001) states that, in Brazil, protected areas are constant changing their land-use and land-cover, starting with deforestation for expansion of the agricultural and urban infrastructure, resulting in pressure on the PPAs, mainly those located along the water courses. The PPA reforestation promotes the formation of vegetation corridors, providing greater gene flow, therefore increasing the chance of survival of the biological communities and their species (PRADO et al., 2003). According to Neiff et al. (2005), this potential is expressed by investigations that highlight the advantages of corridors formed by ciliary forests.

Analysis of the Reforestation scenario using landscape metrics

The map of High and Very high environmental vulnerable regions in the RMG was used to indicate the priority areas for reforestation, recommending the reforestation of an area of 123,857.62 ha, which represents an increase of 41% in the forest land-cover (Figure 4).

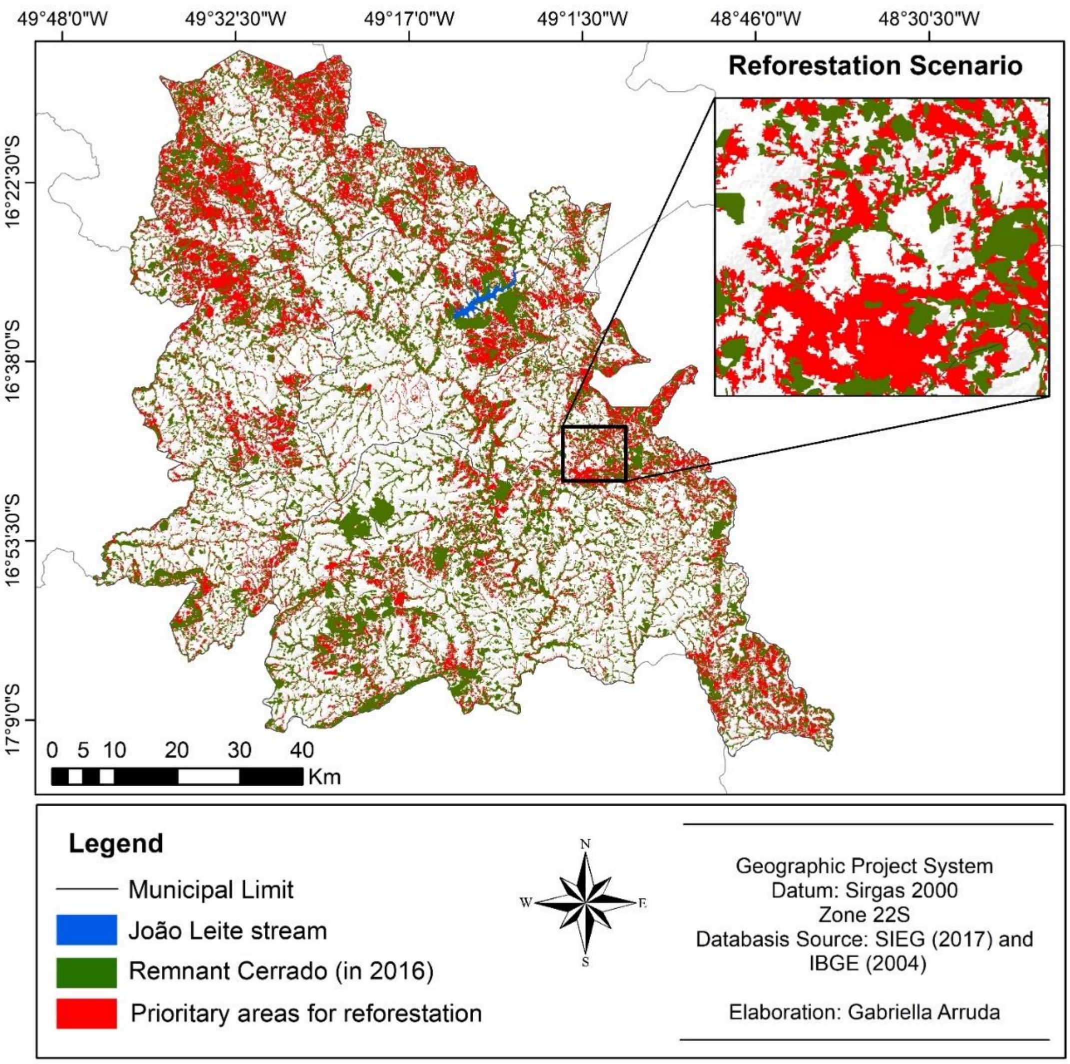
In this third simulated scenario (Reforestation), the landscape metrics were analyzed considering the current scenario of remnant vegetation in the RMG, plus Reforestation areas (simulated). The results indicated a total area (CA) of 297,305.38 ha of plant cover. The plant growth of these priority areas represents greater soil protection against erosive processes, providing the link between one or more fragments, besides contributing to the conservation of the already existing fragments (GARCIA et al., 2013; COSTA et al., 2014). The NUMP was 5,034, that is, 18% lower than the current scenario. In this reforestation scenario, this reduction resulted from the union of one or more fragments, due to the adding of vegetation (123,857.62 ha), resulting from the simulation. The largest fragment in the landscape (remaining reforestation) has 207,362.77 ha (CA), which corresponded to 69% of interlinked plant area.

The MPS was 59.06 ha, which would be greater than the current and the PPA scenarios. The species diversity decreases when the fragment area becomes smaller, which reveals the importance of the size of the areas for the structural complexity of the fragment. However, larger fragments joined by ecological corridors (formed by the ciliary forests) are a refuge for the wildlife (SAUNDERS et al., 1991; COLLINGE, 1998; ITCO, 2008) and are able to maintain the water resources.

The MNN was 310.88 m, the highest proximity between the fragments. The reduction of the mean distance between the fragments is the result of the restoration of connectivity, which makes it possible to connect two or more fragmented habitats, restoring biological flow and reducing the risk of extinction (MYERS; BAZELY, 2003; AWADE & METZGER, 2008).

The MSI was 2.01, which revealed a slight improvement, even lower than the PPA scenario. These results were attributed to the fact that high-vulnerability environmental zones are broken or merged with low-vulnerability zones, making polygons more irregular. The most irregularly shaped fragments are generally less recommended for conservation since they usually have a larger border area (KURASZ et al., 2008), making them more susceptible to burning, wind, or even deforestation.

Figure 4 - Simulation of the Reforestation scenario, indicating the locations of High and Very high vulnerability without vegetation cover (to be recovered).



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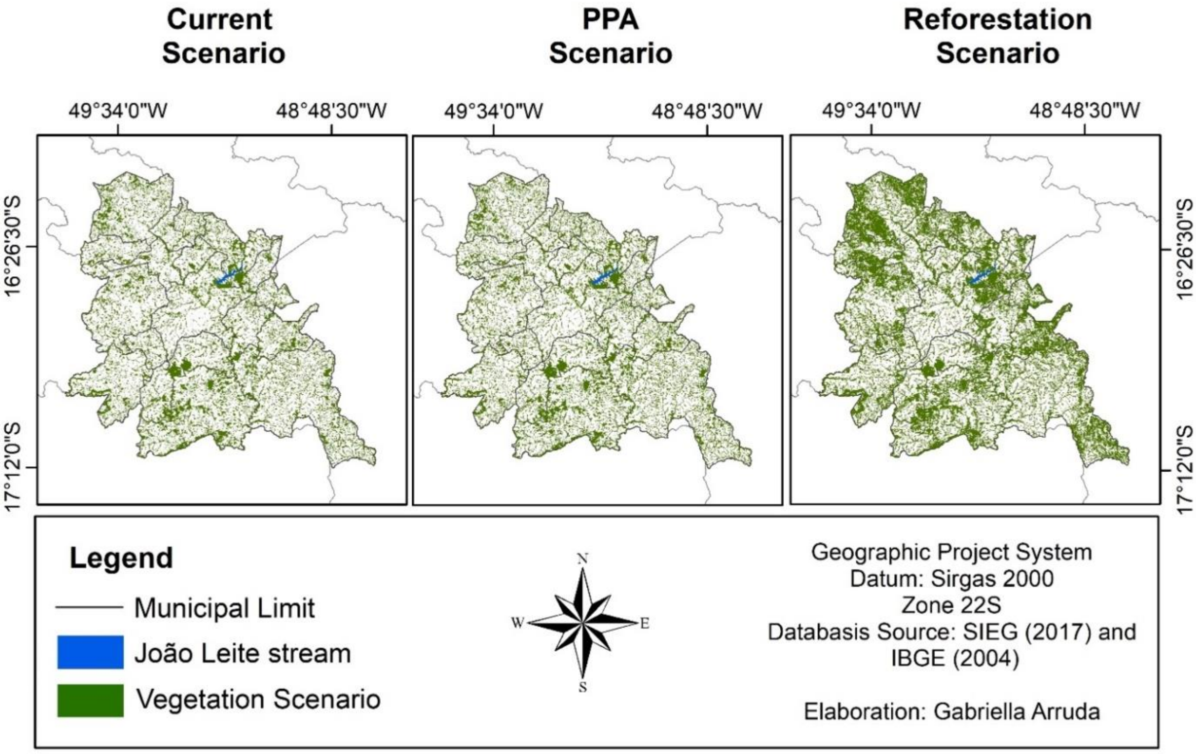
Comparison between the Current, PPA, and reforestation scenarios

Comparing the different scenarios, the PPA presented the number of fragments reduced, but with an increase in the reforested area, which allowed us to infer the increase in connectivity between the habitats. Thus, the PPA scenario presents the lowest susceptibility to the edge effect, expressed in the MSI, with a value closer to 1, that is, closer to the circular shape. The reforestation scenario exhibited an improvement in the connectivity of the landscape, expressed from the MNN. It is also higher than the ones found in the current and PPA scenarios regarding the CA, with a greater forest increment in the areas of greater vulnerability, and a larger MPS. In general, there is a decrease in forest fragmentation in the PPA and reforestation scenarios, compared to the current scenario of the RMG landscape. In Figure 5, the three scenarios show the gradual increase of vegetation as proposed in each scenario, with an increase of 33% in native vegetation from the current to the PPA scenarios, and of 41% from the current to the reforestation scenarios.

Figure 5 - Actual, APP and Reforestation Scenarios, with locations without vegetation cover (to be recovered).



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Considering the soil loss analysis after the PPA and Reforestation scenarios, the two scenarios have coincident areas (the final result is not exactly the sum of the PPA and Reforestation scenarios), indicating an increase of 131,694.46 ha of native vegetation for the RMG region.

The comparison between Based on the simulation of reforestation of areas of high and very high vulnerability and APP recovery, the potential for laminar erosion of the RMG for the "forest restoration" and a scenario was calculated, making it possible to compare with the condition current loss of soil allowed us to observe that, in this scenario (PPA + Reforestation), most of the soil loss (73.52%) was lower than 10 t ha^{-1} year^{-1}, according to the FAO class division (1967), which is considered a low erosive potential, as shown in Table 1.

Table 1. Classification of the degree of erosion by scenarios (Current and APP + Reforestation) in the Metropolitan Region of Goiânia (RMG).

Class	Loss of soil t ha^{-1} year^{-1}	Current scenario		PPA + Reforestation scenario	
		Area (ha)	%	Area (ha)	%
Low	0 to 10	399,070	54.56	537,643	73.52
Medium	10 to 50	303,344	41.48	189,997	25.98
High	50 to 200	28,886	3.95	3,660	0.50
Very high	> 200	0.00	0.01	0.00	0.00
Total	-	731,300.00	100.00	731,300.00	100.00

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The increase of 131,694.46 ha native vegetation reduces the soil loss by 34% (9.80 to 6.50 t ha^{-1} $year^{-1}$). In other words, the increase in forest vegetation reduces the erosive potential, with greater protection to the soils and, consequently, to the most vulnerable areas, highlighting the strong association between plant cover and soil conservation.

Soil degradation by laminar water erosion loads pollutants into the water courses, such as nutrients, organic materials, and pesticides, resulting in poor water quality (DESCROIX et al., 2008; SANTOS et al., 2010). The loss of nutrients in agriculture increases the use of fertilizers and pesticides, among others, which results in the increase of pollution of the water resources. In our study, it is clear that the presence of native vegetation reduces the soil laminar erosion, with the riparian vegetation being useful as a barrier to leaching.

The simulation of reforestation in environmentally vulnerable areas, including the PPAs and water springs, highlights that the impact could be avoided in these possible scenarios. In addition, the depth of the water table was considered – aiming at the protection of the underground waters – and the soil conservation factor was especially included in the environmental vulnerability map (LIMA et al., 2018).

FINAL CONSIDERATIONS

According to the current landscape configuration of the Metropolitan Region of Goiânia (RMG), we have found that the Cerrado remnants are highly fragmented, and their maintenance and conservation should be a fundamental goal, whereas the reforestation of the vulnerable areas and PPA is highly recommended. Based on the five metrics evaluated in the three scenarios (two of them hypothetical), part of these fragments may be considered fragile, given their ecological functions, since they shelter large animals, protect water resources, and stabilize the soil.

By adopting the "PPA" scenario, simulating the addition of forest vegetation to the current scenario, the connectivity increased, which represented a considerable improvement in the protection of water courses. The recovery of the areas indicated in the "reforestation" scenario would increase the forest cover. In this scenario, the increase in the average size of the fragments was observed, in addition to the improvement in the other metrics. This increase in forest vegetation warrants the vegetation coverage of the "Very high" and "High" environmental vulnerability regions, and the maintenance of the priority fragments.

In addition, the great reduction in soil loss by laminar erosion is added to these results. If compared to the land use map for 2016, the "Permanent Protection Areas" and "Reforestation" scenarios caused a significant reduction in soil loss. In this sense, this work stresses the importance of the remaining not fragmented vegetation as a soil loss mitigating factor.

Finally, the scenario simulation may contribute to a better management of this region, by simulating the connection among the forest fragments, showing an increase in their average size, and a consequent increase in the shape index, besides pointing to a greater soil conservation. The spatialization of these results, and the indication of areas for reforestation and conservation, act as a guideline to public policies and in collective decision-making, involving all the municipalities of the RMG.

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