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Papers

Identification of land use conflicts in Permanent Preservation Area in a Brazilian Amazon sub-basin

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Abstract
The southern region of the Amazon stands out for the growing agricultural development and installation of large hydroelectric projects. Given this scenario, the objective of this study was to quantify the Áreas de Preservação Permanente (APPs), Permanent Preservation Areas, of the water bodies of the Teles Pires river basin according to the current legislation, checking whether there is conflict regarding the use and occupation of these areas, and then check for the occurrence of degradation and identify the environmental fragility of the area. Using the Modified Normalized Difference Water Index (MNDWI), the water bodies located in the study area were delineated and the APPs were delimited according to Law 12,651/2012. To identify the existence of conflicts within these areas, a map of land use and occupation was generated through Maximum Likelihood supervised classification, which was compared with the limits of the APPs, considering conflict areas whose land use is related to anthropic activities. Lastly, the potential and emerging fragility of the area were calculated, considering data of the slope, soil type and land cover/land use. The delimited APP comprised 3.96% of the total area of the basin and it showed a state of low degradation, with 83.83% of the area conserved under native vegetation cover and 15.93% showing conflicting type of use, with the occupation by pastures standing out, and among the APP categories mapped the headwaters were the most impacted. The spatialization of conflicts within the basin indicated that it has a very different conservation pattern, with the most critical areas concentrated in the center-east, where municipalities that have more than 40% of the APP occupied by anthropic activities are located. The north of the basin has areas with higher potential fragility, which is attenuated by the great soil protection.

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INTRODUCTION

The management of natural vegetation in Brazil is guided by a set of laws called the Forest Code (BORGES et al., 2011). Since the Código Florestal (which means Forest Code in English) of 1965 (Law 4,771/1965), some areas were categorized as Áreas de Preservação Permanente (APPs), Permanent Preservation Areas (OLIVEIRA; CEASES; OLIVEIRA, 2020). In the current Código Florestal, Law 12,651/2012, these areas are defined as protected areas whose environmental role is to preserve water resources, geological stability, biodiversity, protect the soil and ensure the well-being of populations, encompassing among their areas the marginal strips of watercourses, surrounding lakes and springs (BRASIL, 2012).

Due to their environmental function, limits are imposed to changes in APPs, and their native vegetation should be maintained, with permission for interventions only in the case of public utility, social interest or low impact (MACHADO et al., 2019). However, the existence of legislation does not prevent the degradation of these areas due to environmental conflicts, such as the accelerated occupation of spaces without planning, resulting in processes harmful to natural environments, with impacts on water resources (CAVALCANTE; LIMA, 2019).

The environmental fragility to which APPs are subjected requires measures to protect these environments, so it is necessary to correctly identify their limits (BARBALHO et al., 2019). Geotechnologies such as remote sensing and geoprocessing have been used to monitor environmental conditions in APPs, providing support in the identification of land use conflicts, monitoring and surveillance of these environments (HAAS et al., 2018). Several studies in Brazil have identified conflicts of the use and occupation of APPs, resulting from the pressure exerted by anthropic advancement (OLIVEIRA et al., 2017; PEREIRA et al., 2016), and the present study is the result of quantification and analysis of APPs in the Teles Pires river basin.

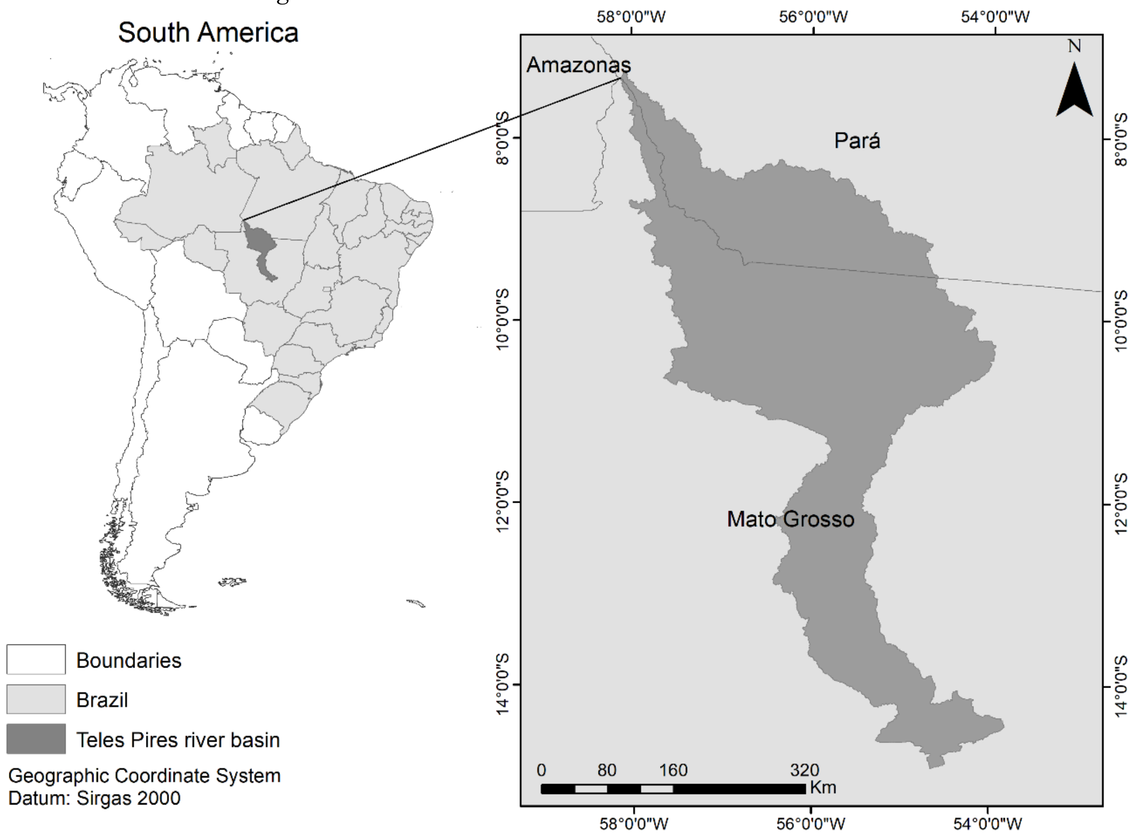
The Teles Pires River basin, located in the states of Mato Grosso and Pará, south of the Legal Amazon, has high economic development due to agricultural expansion. The inventory carried out by Eletrobrás identified in the region potential for power generation, establishing a set of hydroelectric uses comprising the Hydroelectric Power Plants (HPPs) Sinop, Colíder, Teles Pires, São Manoel, Foz do Apiacás and Magessi (GALLARDO et al., 2017). The first four had already their reservoirs implemented when this study started.

Seeking to evaluate the changes in land use associated with recent agricultural occupation in APPs areas have potentiated environmental fragility, this study aimed to quantify the APPs of the water bodies of the Teles Pires river basin according to current legislation, checking whether there is conflict regarding the use and occupation of these areas, and then check for the occurrence of degradation and identify the environmental fragility of the area.

MATERIAL AND METHODS

The study area corresponds to the Teles Pires river basin, located between latitudes 7º 16’ 47” and 14º 55’ 17” South and longitudes 53º 49’ 46” and 58º 7’ 58” West (Figure 1), covering a territory of 141,524 km² located in the Amazon hydrographic region, having Teles Pires as the main river, one of the rivers that form the Tapajós River.

Figure 1 - Location of the Teles Pires river basin.



Source: The authors (2021).

Encompassing domains of the Amazon and Cerrado, the Teles Pires river basin has vegetation characteristic of both biomes, as well as transition areas. The climates found in the region according to Köppen's classification are Aw, tropical with dry winter, predominant in the basin, and Am, humid tropical with a dry season of short duration, occurring near the mouth.

The study was carried out using scenes of the Operational Land Imager - OLI, Landsat 8 satellite, obtained free of charge as Level 1 products of the United States Geological Survey - USGS (2020), with a spatial resolution of 30 meters, with 14 scenes required for covering the area, for the year 2020 (Table 1).

Table 1 - Orbit/point and dates of the scenes used.

Orbit	225	226	227	228	228	229
Point	70	66; 67; 68; 69; 70	66; 67; 68; 69	65; 66	67	65
Date	06/10/2020	07/03/2020	07/10/2020	07/17/2020	06/15/2020	06/22/2020

Source: The authors (2021).

In order to delimit the area of study, the Digital Elevation Model (DEM) was acquired, made available by the Empresa Brasileira de Pesquisa Agropecuária – EMBRAPA (2005), responsible for enabling research, development and innovation solutions for the sustainability of agriculture, which is based on data from the SRTM (*Shuttle Radar Topography Mission*) mission with a spatial resolution of 90 meters. Vector data from the municipal boundaries and drainage network of the Brazilian territory were also obtained from the continuous cartographic base of the Instituto Brasileiro de Geografia e Estatística - IBGE (2017), country data and information provider, 1:250,000 scale, and the limits of the Water Planning Units of the Agência Nacional de Águas - ANA (2017), which is the federal agency responsible for the implementation of Brazilian water resources management, which divides the basin into upper, middle and lower Teles Pires, later adapted to the limit generated in the delimitation of the area.

ENVI, ArcGis 10.1 and Google Earth Pro software programs were used in the data processing.

The DEM and the drainage network were used to delimit the study area with the *ArcHidro* extension in *ArcGis*. The DEM was reconditioned based on the AGREE method and has undergone correction of depressions. Next, the following parameters were generated: flow direction by the *Eight Direction Pour Point Model* method, the accumulated flow, and the raster drainage network using the threshold of 250 cells of accumulated flow. Finally, the basin was delimited based on the discharge point comprising the mouth of the Teles Pires river.

Delimiting the APPs of the water bodies required information on their distribution in the area, and it was chosen to use the Modified Normalized Difference Water Index (MNDWI) based on Landsat scenes. MNDWI uses the spectral bands of green and mid-infrared to delineate water surfaces based on the reflectance contrasts of the targets (XU, 2006), showing good results in the extraction of water features (ALI; HASIM; ABIDIN, 2019).

The application of spectral indices requires the use of reflectance values (LI; JIANG; FENG, 2014), so Landsat scenes were prepared in ENVI software, with the conversion of spectral band values to reflectance at the top of the atmosphere and atmospheric correction with the FLAASH module (Fast Line-of-sight Atmospheric Analysis of Spectral Hypercubes) based on the MODTRAN (Moderate Resolution Atmospheric Transmission) radiative transfer model, delivering surface reflectance data (PRUDÊNCIO et al., 2019).

After selecting the bands corresponding to the spectral bands of the green and mid-infrared, bands 3 (0.53-0.59 µm) and 6 (1.57-1.65 µm) of the OLI sensor, they were entered into *ArcGis* and the raster calculator was used to obtain the MNDWI through equation 1 (XU, 2006).

$$MNDWI = \frac{Band\ 3 - Band\ 6}{Band\ 3 + Band\ 6} \quad (1)$$

Knowing that positive values comprise water-covered areas (ZHOU et al., 2017), these were individualized and converted to vector format, constituting polygons representing water bodies, which were classified, generating clusters equivalent to those expressed in the current Código Florestal Brasileiro (Brazilian Forest Code) (BRASIL, 2012). The classification consisted of the identification of watercourses and separation into width intervals and identification of lakes and their areas, separating them into up to 20 hectares and larger, rural or urban, natural or artificial.

The omission of many watercourses due to the limitation imposed by the spatial resolution of the scenes and the presence of dense gallery forests led to the use of the vector drainage network to delineate a greater number of water bodies. After verifying the lack of detailed scale data with full coverage for the area, the IBGE drainage network was used, 1:250,000 scale, which allows for an average error of up to 125 meters, acceptable for the scale, but which implies positional errors when compared with Landsat scenes. To correct these errors, manual edits were made in some segments of the drainage vector, after a thorough inspection of the layer superimposed on satellite images and identification of the places where the displacements of the drainage network were visible. The watercourses identified at this stage were considered smaller than 10 meters wide due to the impossibility of extracting real widths.

Finally, the springs were demarcated, creating a vector of points located at the beginning of the watercourses.

The APPs were delimited using the buffer tool, respecting the widths set by the current Código Florestal, legislation that determines how vegetation should be treated in Brazil, Law 12,651/2012 (BRASIL, 2012), and adopting for artificial lakes the minimum values set in the document (Table 2).

Table 2 - Widths of APPs of the water bodies.

Widths of water bodies (meters)	APP (meters)	Lakes or Reservoirs	APP (meters)
Less than 10	30	Natural - rural area	100
10 to 50	50	Natural - rural area (up to 20 ha)	50
50 to 200	100	Natural - urban area	30
200 to 600	200	Artificial	30
More than 600	500	Artificial - rural area (up to 20 ha)	15
Springs	50 (radius)	Artificial - urban area	15

Source: Código Florestal, Law 12,651/2012 (BRASIL, 2012).

To check for the existence of conflicts regarding land use in the APPs, a map of use and occupation was generated using the supervised classification of OLI scenes in surface reflectance values, which were subjected to mosaic composition and RGB 654 color composition (Mid-Infrared, Near Infrared and Red). The Maximum Likelihood classification method was used, recognized by good performance (VALE et al., 2018), which uses previously identified information to classify all pixels of the scenes, calculating the probabilities (ALI; QAZI; ASLAM, 2018).

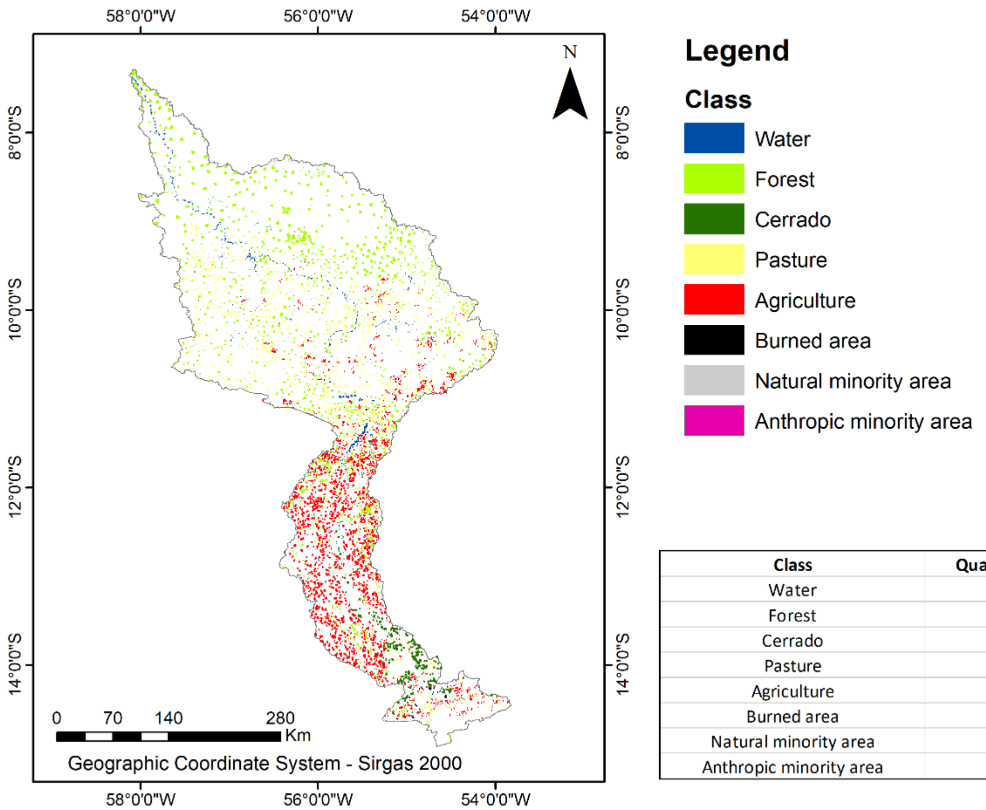
The selection of samples for training was performed using techniques of visual interpretation of images, facilitated by the prior knowledge of the forms of use and occupation present in the basin, resulting in the mapping of eight classes of land use and occupation within the area (Table 3). The training sample sets were distributed throughout the basin area, both of which with more than 3,500 pixels per training class (Figure 2).

Table 3 - Classes of land use and occupation mapped in the Teles Pires river basin.

Water	Surfaces covered by water.
Forest	Tree forest vegetation with a high density of trees.
Cerrado	Vegetation with the predominance of shrubby stratum and areas of low-density forest formation.
Pasture	Surfaces composed of natural or planted perennial fodder crops, intended for grazing livestock.
Agriculture	Cultivated areas used for the production of food, fiber and agribusiness commodities.
Burned area	Surfaces that have undergone recent burning processes.
Natural minority areas	Include sandbanks and rock formations.
Anthropic minority areas	Include urban and mining areas.

The authors (2021).

Figure 2 - Distribution and value of training samples per class mapped in the Teles Pires river basin.



Class	Quantity of pixels
Water	176056
Forest	3534967
Cerrado	146935
Pasture	779909
Agriculture	3002893
Burned area	22673
Natural minority area	3931
Anthropic minority area	6056

Source: The authors (2022).

By overlapping the maps of the classification and of APPs, the classes of land use and occupation present in these areas were extracted, considering areas of conflict those related to anthropic use, since the legislation determines that the APPs must be maintained in natural condition.

To estimate the quality of the classification inside the APPs, samples of ground truth were collected, identifying 1,279 points distributed among the classes inside the buffer. The points were manually identified by visual interpretation of high-resolution images in Google Earth Pro and compared with classification data. Then, an error matrix was created and the Kappa Index (COHEN, 1960) and the Overall, Producer and User Accuracies (CONGALTON, 1991) were calculated.

In order to evaluate the spatial distribution of conflicts in the APPs along the basin, the area was compartmentalized into the upper, middle and lower Teles Pires and municipal limits, and the evaluation of the degradation of APPs was based on the percentage of conflict areas. This study did not consider the criterion of consolidated areas in APPs, which authorizes the continuity of consolidated activities until 2008, allowing the partial recovery of the areas.

Finally, the environmental fragility of the area was calculated using an adapted methodology based on the empirical analysis of the fragility of natural and anthropized environments of Ross (1994). The variables used in the analysis involved slope, soil types and land cover/land use. The slope was generated from the Topodata DEM (INPE, 2011), the identification of soil types was obtained from Embrapa's database in vector format (GEOINFO, 2020), and the land cover/land use used was the one generated in the previous step. These three variables were hierarchized into five different classes according to their vulnerabilities, receiving weights from 1 to 5 (Table 4).

Table 4 - Classes of fragility of slopes and soils and classes of protection by land cover/land use.

Weight	Degree of fragility	Slope (%)	Type of soil	Degree of soil protection	Land cover/land use
1	Very Low	0 to 6	-	Very High	Forest
2	Low	6 to 12	*Latossolo Vermelho* and *Vermelho-amarelo* (Oxisol)	High	Cerrado
3	Medium	12 to 20	*Argissolo Vermelho* and *Vermelho-amarelo* and *Nitossolo Vermelho* (Ultisol)	Medium	Pasture
4	High	20 to 30	*Cambissolo Háplico* (Inceptisol) and *Plintossolo Pétrico* (Plinthic subgroup)	Low	Agriculture
5	Very High	>30	*Gleissolo Háplico* and *Neossolo Flúvico*, *Litólico* and *Quartzarênico* (Entisol)	Very Low	Burned area, Natural and anthropic minority areas

Source: Adapted from Ross (1994) and Pires et al. (2015).

The environmental fragility maps were constructed using the map combination method called weighted overlay, through the Weighted Overlay tool, assigning equal percentages of influence to each of the variables. The combination of the slope and soil variables originated the map of potential fragility, which considers only natural aspects; this map, in turn, was combined with the land cover/land use map to generate the emerging environmental fragility map.

RESULTS AND DISCUSSION

In the Teles Pires river basin, there was a total of 5,607.36 km² of APPs linked to water bodies, which corresponds to 3.96% of the basin. When mapping similar APP categories, Nunes et al. (2015) found an area equivalent to 11.10% in a micro-basin in northern Mato Grosso, while Pereira et al. (2016) found an area equivalent to 2.80% when mapping a basin in the state of Pará. Different proportions of APPs result from different local characteristics, such as relief and drainage, as well as the scale of the data used (SANTOS et al., 2017).

In the Legal Amazon, the unavailability of detailed scale data with wide territorial coverage (SANTOS; BUENO; SAMPAIO MOREIRA, 2015) requires the search for new alternatives for data acquisition. The MNDWI, used in this study, proved to be a viable option as it made it possible to delineate water bodies, but its potential was limited by the resolution of satellite images, being effective in the delimitation of large water bodies.

The map of land use and occupation generated for the area identified a predominance of native vegetation, occupying 59% of the basin, covering the forest and Cerrado classes. Among the classes of anthropic use, two stood out: pasture, occupying 21.90%, and agriculture, occupying 17.10%. The classes water, burned area and the natural and anthropic minority areas showed low percentages, equal to 0.8%, 0.1%, 0.2% and 0.4%, respectively.

The validation of the classification, performed only inside the APPs and water bodies (Table 5), indicated that the User Accuracy, which is the probability of the mapped area representing the category in the terrain, was higher for the classes of natural and anthropic minority areas, water, Cerrado and pasture, while the Producer Accuracy, which is the probability of the actual area being correctly represented on the map, was higher for water, natural minority areas, forest, pasture and agriculture. The main confusion identified results from the omission of Cerrado areas, erroneously classified as forest; however, as both represent natural formations, this error does not imply improper identification of conflicts. Overall Accuracy was 91.16% and the Kappa Index was 0.89, which is considered excellent (LANDIS; KOCH, 1977).

Table 5 - User accuracy and producer accuracy of the classes mapped in the APPs of the Teles Pires river basin.

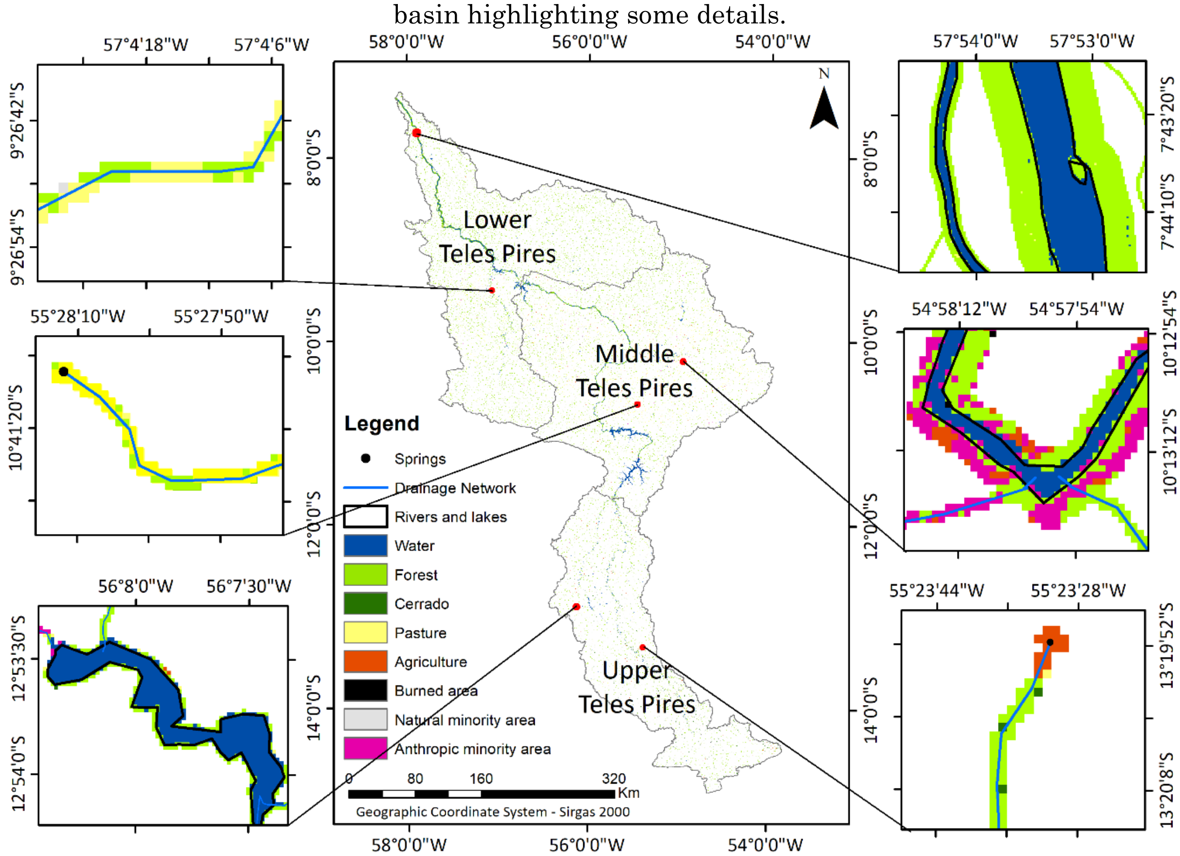
Class	Water	Forest	Cerrado	Pasture	Agriculture	Minority areas Natural	Minority areas Anthropic
Samples	221	380	269	217	119	26	47
User Accuracy (%)	99.10	82.78	98.93	92.34	89.68	100.00	97.62
Producer Accuracy (%)	100.00	98.68	68.77	94.47	94.96	100.00	87.23

Source: The authors (2021).

Through the map of land use and occupation in the APPs, it is possible to highlight some segments (Figure 3) and detail the values corresponding to the area occupied by each class and region of the basin (Table 6).

The results showed that 83.83% of the APPs are conserved under natural vegetation, represented by the forest and Cerrado classes, especially the lower and upper Teles Pires, where the percentages are higher. A high percentage of conservation of APPs was also recorded by Oliveira et al. (2017) when mapping an area in western Bahia, recording 95.65% of the APPs occupied by natural vegetation in 2010.

Figure 3 - Map of land use and occupation within the APPs of the water bodies of the Teles Pires river basin highlighting some details.



Source: The authors (2021).

Table 6 - Areas of land use and occupation in the APPs of the Teles Pires river basin and respective regions.

Class	Teles Pires river basin		Regions					
			Upper Teles Pires		Middle Teles Pires		Lower Teles Pires	
	Km²	%	Km²	%	Km²	%	Km²	%
Forest	4,551.90	81.18	708.79	74.26	1,617.87	73.20	2,225.24	91.10
Cerrado	148.67	2.65	148.67	15.58	-	-	-	-
Pasture	726.03	12.95	50.89	5.33	488.90	22.12	186.24	7.62
Agriculture	109.35	1.95	42.22	4.42	63.41	2.87	3.71	0.15
Burned area	13.79	0.25	2.25	0.24	11.53	0.52	0.01	0.00
Natural minority area	13.43	0.24	0.00	0.00	0.00	0.00	13.43	0.55
Anthropic minority area	44.19	0.79	1.65	0.17	28.59	1.29	13.95	0.57

Source: The authors (2021).

Regarding the existence of conflicts in the APPs, 15.93% of the area was identified under some form of anthropic use, and pasture stood out with 12.95% of occupation of APPs in the basin, followed by agriculture with 1.95%. A higher percentage of conflicts was recorded in the middle Teles Pires, which is characterized by the strong presence of livestock farming activity. A similar situation is reported by Mascarenhas, Ferreira and Ferreira (2009), who mapped 14,250 km² of APP in the Araguaia River basin and identified 44.58% of degraded area, mainly in the upper and middle course of the river, associating it with livestock farming activity. Pasture was also pointed out as responsible for the degradation of APPs in a study conducted by Nunes et al. (2015) in a micro-basin of the Teles Pires.

The substantial occupation of APPs by pasture is explained by the use of the extensive livestock farming model in the region, large cattle herds (WEIHS; SAYAGO; TOURRAND, 2017) and the use of water bodies for animal watering. Although the Código Florestal allows the access of animals to APPs to obtain water (Article 9, Law 12,651/12), this has favored the deforestation of these areas and the progressive expansion of pastures into the core of the APPs (MASCARENHAS; FERREIRA; FERREIRA, 2009).

Considering the different categories of water bodies mapped in the basin, it was found that the springs were the most impacted, as 29.35% of the APPs showed improper use (Table 7). Cocco et al. (2016), when mapping the APPs of the springs of a sub-basin of the Juruena river, also located in the Legal Amazon, found 41.34% degradation in that area in 2014. This scenario is alarming, because the degradation of these environments compromises the replenishment of the water table, generating quantitative and qualitative impacts on water (PESSI et al., 2019).

Table 7 - Conflict areas in the APPs of the different categories of water bodies in the Pires Teles river basin.

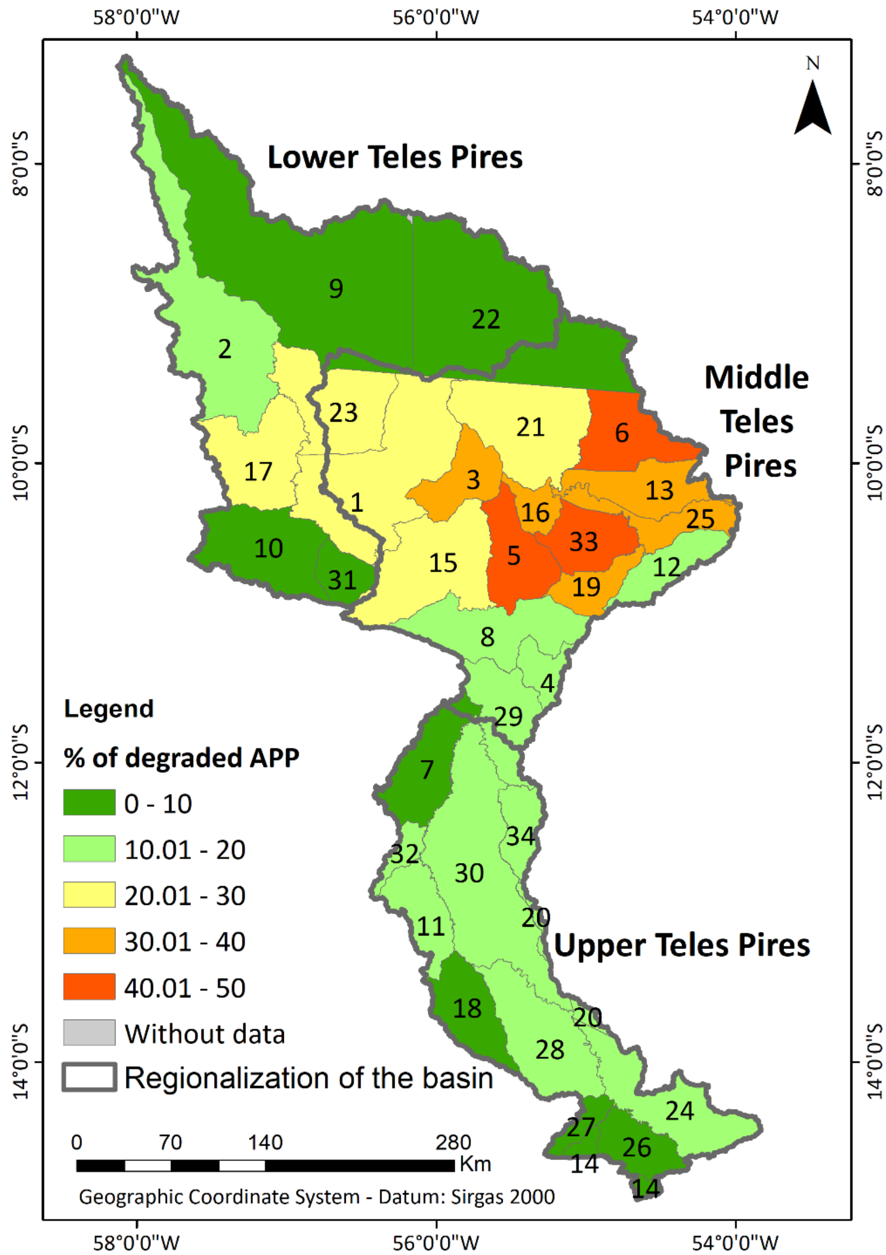
Category	Water bodies	Springs	Natural Lakes	Artificial Lakes	HPP Lakes*
Total proportion of APP (%)	96.38	2.18	0.05	1.39	1.03
Conflict areas (%)	15.06	29.35	2.98	21.90	18.69

*HPP lakes: lakes of the hydroelectric projects; these values are also counted in artificial lakes. Source: The authors (2021).

Despite the low percentage of degradation of APPs found in the Teles Pires river basin, this is still worrisome, since the degradation of these areas compromises the environmental services provided by them. These areas are fundamental in controlling soil erosion and water quality, reducing contamination of aquatic environments (DOMINGUES et al., 2015) and, around artificial reservoirs, they help to extend their useful life (MOREIRA et al., 2015).

The mapped APPs are within the territories of 34 different municipalities, and these were classified according to the percentage of degraded APP, considering the number of conflicts (Figure 4 and Table 8).

Figure 4 - Classification of the municipalities within the Teles Pires river basin according to the percentage of degradation of the APPs.



Source: The authors (2021).

Table 8 - Identification of the municipalities within the Teles Pires river basin in which the mapped APPs are located.

N. Id	Municipality	% mun/basin	% APP mun/total	Id. N.	Municipality	% mun/basin	% APP mun/total
1	Alta Floresta	100	7.54	**18**	Nova Mutum	30.16	0.95
2	Apiacás	44.93	10.30	**19**	Nova Santa Helena	69.95	0.86
3	Carlinda	100.00	2.25	**20**	Nova Ubiratã	4.72	0.25
4	Cláudia	31.73	0.72	**21**	Novo Mundo	100	4.30
5	Colíder	100	2.20	**22**	Novo Progresso	35.90	8.88
6	Guarantã do Norte	70.46	2.22	**23**	Paranaíta	100.00	5.29
7	Ipiranga do Norte	98.78	1.74	**24**	Paranatinga	18.84	1.96
8	Itaúba	97.35	2.88	**25**	Peixoto de Azevedo	15.22	1.35
9	Jacareacanga	34.33	15.90	**26**	Planalto da Serra	85.02	0.95
10	Juara	20.94	3.01	**27**	Rosário Oeste	11.11	0.44
11	Lucas do Rio Verde	67.26	0.97	**28**	Santa Rita do Trivelato	99.91	2.74
12	Marcelândia	18.05	0.86	**29**	Sinop	81.06	1.46
13	Matupá	58.42	1.80	**30**	Sorriso	98.37	4.87
14	Nova Brasilândia	18.89	0.28	**31**	Tabaporã	17.63	1.08
15	Nova Canaã do Norte	99.77	4.89	**32**	Tapurah	17.77	0.34
16	Nova Guarita	100	0.78	**33**	Terra Nova do Norte	100	1.48
17	Nova Monte Verde	82.75	3.82	**34**	Vera	55.98	0.64

Id. N.: identification number of the municipality related to the map; % mun/basin: percentage of the municipality that is within the Teles Pires river basin; % APP mun/total: percentage of APP of the municipality corresponding to the total APP of the basin. Source: The authors (2021).

Nine of the municipalities recorded a percentage of degradation of APPs below 10%, covering 33% of the total of the APPs. Twelve municipalities had between 10.01% and 20% of degraded APP and five had between 20.01% and 30%, representing 28% and 26% of the total of APPs, respectively. The remaining municipalities comprised about 13% of the total of APPs and had between 30.01% and 50% of degradation.

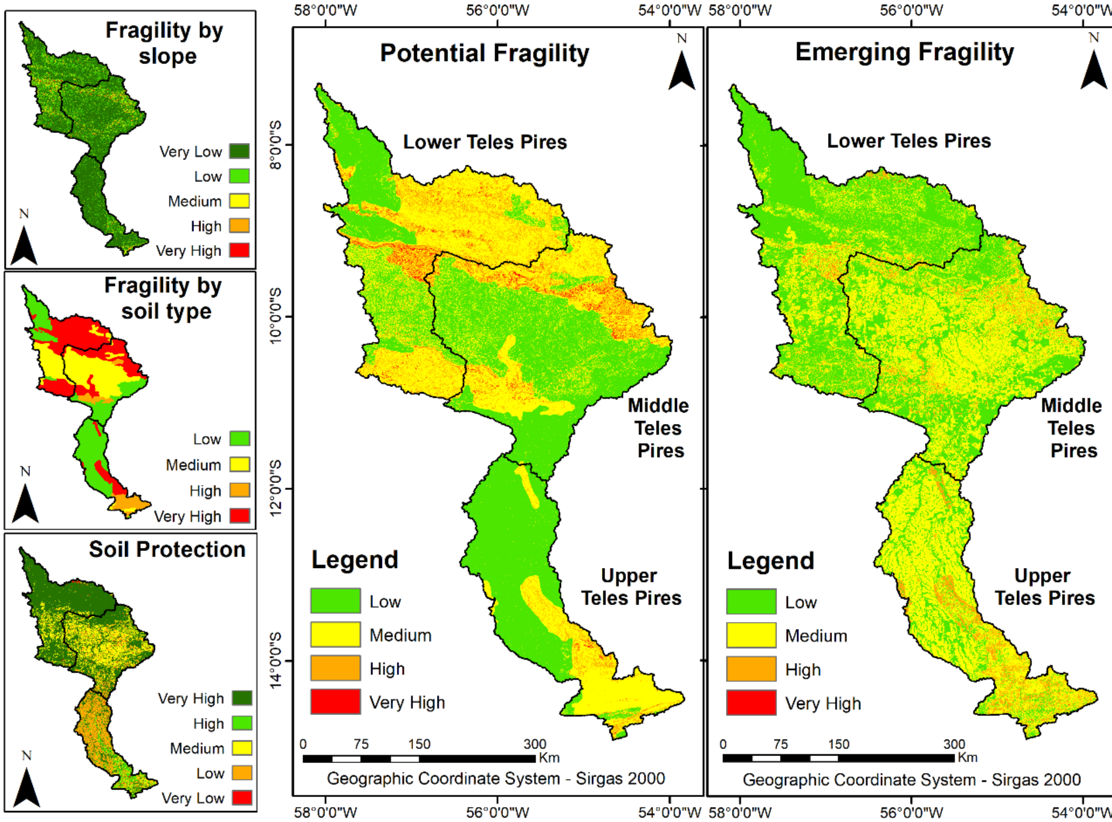
Of the municipalities with low degradation, some are located near the mouth of the basin, favored by the low human occupation and presence of protected areas, while the others are located in the upper Teles Pires, a region of occupation already consolidated and with intense agricultural development, so the low degradation of the areas may be associated with a project developed to support the restoration of APPs. This project benefits municipalities such as Lucas do Rio Verde, Nova Mutum, Nova Ubiratã, Sorriso and Tapurah, being the result of a partnership between municipalities, rural producers and the American NGO *The Nature Conservancy,* helping farmers in adjusting their properties to environmental legislation (TIMOTHEO et al., 2016).

It is in the center-east of the basin that the municipalities with a high percentage of degraded APP are concentrated, especially Guarantã do Norte, Terra Nova do Norte and Colíder, where 40.01% to 50% of the APPs have conflicting use. Bernasconi, Mendonça and Micol (2009), when mapping the APPs of Colíder in 2008, indicated 60% of degradation, and the precarious situation of the APPs of this municipality has also been reported by Nobre, Roque and Bampi (2013). The municipalities of this region historically have livestock farming as their main economic activity (LOVATO, 2017), where there is also a Mining Reserve that encompasses municipalities such as Peixoto de Azevedo, Novo Mundo, Nova Guarita, Matupá, Marcelândia, Terra Nova do Norte and Nova Santa Helena (MASSARO; THEIJE, 2018), with activity characterized by being conducted on the banks of rivers, resulting in erosive processes (SOUZA et al., 2008) and degradation of APPs.

Although the municipalities with a high percentage of degradation of APPs represent a small portion of the basin, these are concentrated in the same portion, indicating the critical condition of the region, highlighting the need for the adoption of measures aimed at the recovery of these areas and regeneration of APPs, in view of the positive effects they have on the maintenance of water resources (VIEGAS; ALMEIDA; SOUZA, 2018). Initiatives such as those undertaken in the upper Teles Pires, if expanded, could favor the recovery of other areas in the basin.

The maps of potential and emerging fragility generated for the Teles Pires river basin resulted in values between 2 and 5, which were identified as low to very high fragility (Figure 5).

Figure 5 - Fragility maps of the Teles Pires river basin.



Source: The authors (2022).

The basin showed a predominance of low and medium fragility, both outside and inside the APPs, with a concentration of areas of higher potential fragility to the north, due to the presence of large extensions of soil with greater vulnerability, and these fragilities in the region are attenuated by the presence of soil covers that guarantee great protection. The presence of protected areas and indigenous territories in the extreme north of the basin, where the Cayabi and Munduruku indigenous lands and a segment of the Parque Nacional do Juruena (Juruena National Park) are located, contributes to this fact.

Among the regions of the basin, higher numbers of areas with emerging fragility ranging from high to very high were recorded inside the APPs in the middle Teles Pires, due to the reduced soil protection in some segments and high vulnerability of the soil type. The upper Teles Pires had the lowest quantity of areas with high fragility (Table 9).

Table 9 - Areas of potential and emerging fragility mapped within the APPs of the Teles Pires river basin and divided by regions: Lower, Middle and Upper Teles Pires.

Class	P.F.	E.F.	Lower T.P.		Middle T.P.		Upper T.P.	
			P.F.	E.F.	P.F.	E.F.	P.F.	E.F.
	Area Km²	Area Km²	Area Km²	Area Km²	Area Km²	Area Km²	Area Km²	Area Km²
Low	3461.38	5017.52	1278.40	2229.04	1575.67	1967.60	607.29	820.86
Medium	2520.06	1395.29	1138.38	518.12	977.23	660.49	404.45	216.67
High	551.81	150.76	344.00	43.68	149.28	79.31	58.53	27.77
Very High	46.62	3.77	29.73	2.96	15.02	0.56	1.88	0.26

P.F.: Potential Fragility; E.F.: Emerging Fragility; T.P.: Teles Pires. Source: The authors (2022).

The Teles Pires river basin, as well as several others located in the Amazon, has been undergoing territorial occupation with the conversion of natural areas to agriculture, not always accompanied by respect for the limits necessary for the conservation of natural resources or the enforcement of compliance with environmental laws. Once the APP is degraded, even if there is a change in the mode of land use, these areas may not be recovered. In this context, studies that characterize the occurrence of these problems in the Amazon region are relevant to give visibility to the issue, assist in the adoption of measures that can enable the recovery of areas and alert to the need for planning and monitoring of the accelerated anthropic expansion in the region.

CONCLUSIONS

The methodology adopted made it possible to identify an area of 5,607.36 km² of APP linked to water bodies, equivalent to 3.96% of the total basin. In general, the degradation of APPs of the water bodies located within the Teles Pires river basin is low, with only 15.93% of the area being occupied by conflicting use. However, the basin is marked by spatial contrasts regarding the conservation of APPs, with more favorable conditions being recorded in the lower and upper Teles Pires. The worst conservation conditions occur in the central-eastern part of the basin, in the middle Teles Pires, where critical percentages of degradation of APPs are recorded, with an urgent need for intervention measures.

The North of the Teles Pires river basin has the areas of highest potential environmental fragility, a condition that is attenuated by the high protection of the soil in the region, resulting from the occupation of land by natural vegetation, which demonstrates the importance of their conservation.

The conflicting forms of land use identified include particularly the occupation by pasture, and the degradation of these areas is related to livestock farming in the region, which has led to the expansion of pasture areas into the core of the APPs.

The springs were the category of water body most impacted by the improper use of land in the Teles Pires river basin, representing a threat to the maintenance and availability of water resources in the region.

This study contributed to identifying degraded areas in APPs, which can be targets of resources and forest restoration programs within the basin.

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AUTHORS' CONTRIBUTION

Aline Kraeski and Frederico Terra de Almeida conceived the study, collected and analyzed the data and wrote the text. Tânia Maria de Carvalho collaborated with data analysis and text writing. Adilson Pacheco de Souza collaborated in data collection and analysis and text writing.