Environmental analysis of land use and occupation in nine watersheds contributing to the Iguaçu River, Brazil

Análise ambiental do uso e ocupação da terra em nove bacias hidrográficas contribuintes do rio Iguaçu, Brasil

Análisis ambiental del uso y ocupación de la tierra en nueve cuencas hidrográficas contribuyentes del río Iguazú, Brasil

Jhony F. M. Silva
ORCID: https://orcid.org/0000-0001-9932-2963
Universidade Estadual do Oeste do Paraná, Brazil
E-mail: jhonyferry@hotmail.com
Max Portuguez Obeso
ORCID: https://orcid.org/0000-0001-5248-4850
Universidade Estadual do Oeste do Paraná, Brazil
Instituto Federal de Educação Ciência e Tecnologia do Tocantins, Brazil
E- mail: maxobeso@ifto.edu.br
Maristela Cavicchioli Makrakis
ORCID: https://orcid.org/0000-0001-7539-9659
Universidade Estadual do Oeste do Paraná, Brazil
E-mail: maristela.makrakis@unioeste.br
Sergio Makrakis
ORCID: https://orcid.org/0000-0002-7868-9034
Universidade Estadual do Oeste do Paraná, Brazil
E-mail: sergio.makrakis@unioeste.br

Abstract
The land use and occupation in watersheds directly influences the water resources, and the vegetation cover is a crucial factor for water maintenance. The objective of this study was to characterize the land use and occupation in nine watersheds of the Lower Iguaçu River (Andrada, Monteiro, Gonçalves Dias, Floriano, Silva Jardim, Cotejipe, Sarandi, Capanema and Santo Antônio sub-basin rivers), using the classification from satellite images. The classification area obtained high accuracy (Kappa coefficient of 99.4 to 99.9%). The Floriano River sub-basin presented the highest degree of environmental preservation, followed by Silva Jardim and Gonçalves Dias River sub-basins, fully or partially inserted in Iguaçu National Park. Monteiro and Sarandi river sub-basins showed the smallest areas of vegetation, and Capanema, Cotejipe, Andrada and Santo Antônio River sub-basins exhibited an intermediate condition. This tendency was verified by the cluster analysis. These results can serve as a baseline for planning, monitoring and management of this area, environmental modeling, conservation of water resources, biodiversity, and environmental services.
Keywords: Water resources; Monitoring; Management; Conservation.

Resumo
O uso e ocupação da terra em bacias hidrográficas influencia diretamente os recursos hídricos, sendo a cobertura vegetal um fator determinante para a conservação dos rios. O objetivo deste estudo foi caracterizar o uso e ocupação do solo em nove bacias do baixo rio Iguaçu (rios Andrada, Monteiro, Gonçalves Dias, Floriano, Silva Jardim, Cotejipe, Sarandi, Capanema e Santo Antônio), utilizando a classificação do uso e ocupação da terra a partir de imagens de satélite. A classificação da área obteve boa acurácia (coeficiente Kappa de 99,4 a 99,9%) e a bacia do Floriano foi a que apresentou o maior grau de preservação ambiental, seguida pelas bacias dos rios Silva Jardim e Gonçalves Dias, integral ou parcialmente inseridas no Parque Nacional do Iguaçu. As bacias dos rios Monteiro e Sarandi possuem as menores áreas da classe vegetação e os rios Capanema, Cotejipe, Andrada e Santo Antônio, encontram-se em uma condição intermediária. A mesma tendência foi verificada pela análise de agrupamento. Os resultados podem servir de linha de base para o planejamento, monitoramento e manejo da área, modelagem ambiental, conservação dos recursos hídricos, da biodiversidade e dos serviços ambientais.
Palavras-chave: Recursos hídricos; Monitoramento; Gestão; Conservação.

Resumen
El uso y la ocupación de la tierra en las cuencas hidrográficas influyen directamente en los recursos hídricos y la cubierta vegetal es un factor determinante para el mantenimiento del agua. El objetivo de este estudio fue caracterizar el uso y la ocupación del suelo en nueve cuencas del bajo Iguaçú (ríos Andrada, Monteiro, Gonçalves Dias, Floriano, Silva Jardim, Cotejipe, Sarandi, Capanema y Santo Antônio), utilizando la clasificación de uso y ocupación de la tierra a partir de imágenes de satélite. La clasificación de áreas obtuvo una buena precisión (coeficiente Kappa de 99,4 a 99,9%) y la cuenca del Floriano fue la que presentó el mayor grado de preservación ambiental, seguida por las cuencas de los ríos Silva Jardim y Gonçalves Dias, insertas total o parcialmente en el Parque Nacional de Iguaçú. Las cuencas de los ríos Monteiro y Sarandi poseen las menores áreas de vegetación y los ríos Capanema, Cotejipe, Andrada y Santo Antônio se encuentran en una condición intermedia. La misma tendencia se verificó mediante el análisis de conglomerados. Los resultados pueden servir de base para la planificación, el seguimiento y la gestión de la zona, la elaboración de modelos ambientales, la conservación de los recursos hídricos, la biodiversidad y los servicios ambientales.
Palabras clave: Recursos hídricos; Vigilancia; Administración; Conservación.

1. Introduction

Remote Sensing, defined as obtaining information about a given object at a distance (Jensen, 2009), makes it possible to map and monitor regions, sometimes inaccessible, for various purposes. The availability of images and advances in digital processing and analysis techniques have made it possible to obtain relevant information about the type, condition, area, dimensions, and others about the areas of interest (Murmu & Biswas 2015).

Advances in remote sensing techniques, plus obtaining data in real time, produce accurate information about land cover quickly and economically (Khalil & Haque, 2018). Thus, the use of remote sensing is an important ally of environmental conservation. The anthropic influence on nature, mainly in hydrographic basins, has become an object of concern for researchers, increasing studies to qualify and quantify the impacts of this occupation (Santos, et al., 2022).

As rates of conversion of natural habitats into anthropogenic landscapes increase, the risks and concerns for environmental conservation also increase (Shimizu, 2007), with water from rivers and river basins occupying a prominent position (Tundisi, 2003, pp. 59-66; Giri, & Qiu, 2016). Agricultural, pasture and urban land use are described as major contributors to the increase of nutrients and sediments to freshwater ecosystems (Uriarte, et al., 2011).

Thus, vegetation cover, especially in riparian zones, plays a significant role in maintaining water quality and ecosystems (Mello, et al., 2010). In this way, prior knowledge of the limits and resilience capacities of natural elements has been required, in relation to land use, in search of sustainable development (Santos, et al., 2022). Given this scenario, geoprocessing techniques are efficient to classify an area in terms of land use and occupation, since they are tools that facilitate the observation of changes in the natural characteristics of the environment, in addition to enabling the understanding of possible causes and effects (Silva, et al., 2021; Valadares, 2017).

In this context, satellite images were used to characterize nine watersheds of the Lower Iguaçu River regarding land use and occupation. The susceptibility of the watersheds to environmental degradation was evaluated using the preserved vegetation as a major conservation criterion. Given the need to maintain and/or increase the resilience of water systems and, consequently, aquatic ecosystems, the maintenance of vegetation is a fundamental requirement, including for the construction of indicators of environmental fragility (Cruz, et al., 2017).
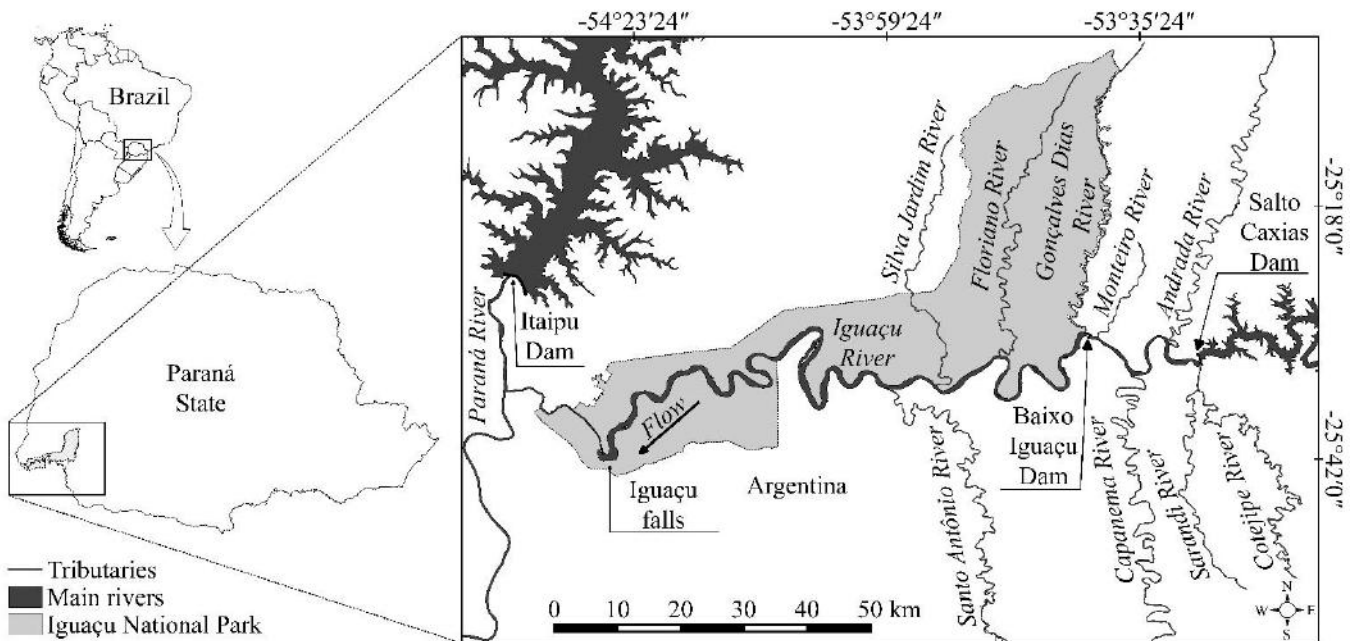
2. Materials and Methods

2.1 Study Area

The study area is in the South America region, on the border between the state of Paraná, in Brazil, and the state of Missiones, in Argentina (Figure 1). It has a humid subtropical climate with hot, humid summers and moderate winters (Köppen,

& Geiger, 1936). The Lower Iguaçu River region has a subtropical climate with an average temperature in the coldest month, below 18°C, and an average temperature in the warmest month, above 22°C (Neto, 2010).

Figure 1: Location map indicating the nine hydrographic basins analyzed in relation to land use in the lower Iguaçu River.

Source: Adapted from (Jhony F. M. da Silva, Elaine Celestino, Guilherme H. B. de Souza, Max P. Obeso, Maristela C. Makrakis, & Sérgio Makrakis, 2022).

The study region corresponds to nine river sub- basins of the Lower Iguaçu River basin, downstream of the Salto Caxias Hydroelectric Power Plant (HPP). The Andrada, Monteiro, Gonçalves Dias, Floriano and Silva Jardim Rivers are tributaries of the right margin. The Cotejipe, Sarandi, Capanema and Santo Antônio Rivers are tributaries of the left margin (Figure 1). The area of about 482,600 hectares is contained in the municipalities of Capanema, Capitão Leônidas Marques, Céu Azul, Matelândia, Nova Prata do Iguaçu, Pérola d'Oeste, Planalto, Realeza, Serranópolis do Iguaçu and Lindoeste.

The sub-basins of the Floriano, Silva Jardim and Gonçalves Dias rivers are part of the Iguaçu National Park (PNI). The PNI is a Conservation Unit (185,262.5 hectares), Federal Decree No. 1,035, of January 10, 1939, created it and had its limits changed by Decree No. 86,676, of December 1, 1981. The area preserves an important forest remnant of the Atlantic Forest Forest (Chico Mendes Institute for Biodiversity Conservation [ICMBIO], 2021).

2.2 Data Collection

The analyses were performed using the Geographic Information System (GIS) QGIS version 2.8 (QGIS, 2015). The delimitation of the Iguaçu River basin and sub-basins were obtained from the National Water Agency (ANA), generated through digital cartography prepared by the States of Paraná and Santa Catarina (ANA, 2015). The data were obtained during the period of the construction of the Baixo Iguaçu hydroelectric plant, implemented from 2013 to 2019, in the Lower Iguaçu River (Figure 1).

Three bands (4 - red, 3 - green and 2 - blue) of an image from the Sentinel-2A Multispectral Instrument (MSI) sensor were used for the supervised multispectral classification, obtained by the European Space Agency (ESA), with spatial resolution of 10 m, in 2016, were used. The programs QGIS 2.8 (QGIS Mapserver 2015) and MultiSpec 3.4 (Biehl, & Landgrebe, 2002)

were used in the analysis of the images. The data obtained from the image processing were used for the classification of land use and occupation and for the grouping of the basins as to environmental preservation area.

2.3 Land Use Classification

The sub-basins were delimited for each river evidenced in the study area, to obtain its total area. After that, the areas of each basin were used to cut the raster in the satellite image, one for each basin. Regarding the Coordinate Reference System (CRS) for the World Geographic System 1984 plan (WGS 84 UTM ZONE 22S), the data were imported into the MultiSpec program for the classification of the selected sub-basins.

Table 1. Land use categories to classify watersheds.

Land use	Description
Urban	Sites containing buildings and soil sealing.
Exposed soil	Area with soil disturbance due to management practices.
Agricultural	Area composed of different cultures, mainly represented by soybean, corn, cassava and oats, and recently harvested sites crops.
Pasture	Soil cover composed of herbs and grasses, used for animal nutrition.
Vegetation	Vegetation areas along aquatic bodies in riparian zones, legal reserves, and other areas of shrub and tree vegetation in the watersheds.

Source: Adapted from (Elaine Celestino, Leandro Celestino, Silva, Kashiwaqui, Maristela Makrakis, & Sérgio Makrakis, 2019).

The areas of interest for each sub-basin were sampled and categorized into (1) urban area, (2) exposed soil, (3) preserved vegetation, (4) agricultural area, and (5) pasture, following the criteria explained in Table 1. The samples were tested using the cross-validation method to internally test the performance of the classification results for each sub-basin (Morin, & Davis, 2016). By this method it is possible to locate and correct discordant samples of the spectral group to improve the effectiveness of the procedure and perform new sampling.

The Maximum Likelihood Method (MAXVER) was used to classify the areas in the image. This is a parametric classifier, which assumes a spatial probability distribution, usually a Gaussian distribution of the data, determining parameters such as mean, and covariance matrix based on spectral sampling data (Brasileiro, et al., 2016).

The classification reliability depends on the adequate choice of spectral samples, which must be representative and composed of pixels with homogeneous characteristics and distributed in classes with good spectral separability (Pinheiro, et al., 2011), among other factors. A low sample size leads the algorithm to allocate pixels in inappropriate classes, increasing the inaccuracy of the classification (Brasileiro, et al., 2016).

The classification was tested by the method of Landis and Koch (1977), which describes the strength according to the Kappa statistic and follows a classification from 0.00 to 1.00. To be considered accurate enough, the classes should obtain a value above 0.80, which represents a nearly perfect classification (Landis & Koch, 1977).

After obtaining the data, the areas of each class (urban, exposed soil, vegetation, pasture and agriculture) were defined in hectares and in percentages. Class patterns regarding land use and occupation were evaluated using Hierarchical Cluster Analysis (Clarke & Warwick 2001; Hair, et al., 2005) using PRIMER v.6 software (Clarke & Gorley, 2006) to compare sub-basins. A similarity matrix was constructed using Euclidean distance, from the data of percentage of urban areas, exposed soil, vegetation, pasture, and agriculture, transformed into square root and normalized. A profile test (SIMPROF) was conducted to

identify the natural structure of groups in the samples (Clarke, et al., 2008). The SIMPROF routine conducts a series of permutation tests to find clusters of samples with significant internal structure (p<0.05; Clarke & Warwick 2001).

3. Results and Discussion

The vegetation class showed occupation of 39.2% of the study area, which indicates a good vegetation cover that, according to the Forest Code of Law No. 12,651 (2012), must be maintained above 35% in the Cerrado biome. However, this coverage is distinct among the sub-basins. The vegetation class was the most representative in the Floriano, Gonçalves Dias and Silva Jardim Rivers. The agricultural class showed predominance in the river sub-basins of the Monteiro, et al. The pasture class was only present in the Capanema River sub-basin. The classes exposed soil and urban area were not very frequent (Table 2; Figures 2, 3A and 3B).

About 45% of the study area is contained within the Iguaçu National Park (PNI), which includes the Floriano, Gonçalves Dias and Silva Jardim River sub-basins, with vegetation cover of 99.31%, 58.31% and 45.89%, respectively - Table 2 and Figures 2, 3A and 3B. The Floriano River sub-basin is entirely contained within the intangible zone of the Iguaçu National Park, which makes it possible to use it as a reference for establishing conservation and monitoring parameters.

The appreciation of the Conservation Unit (Iguaçu National Park) and the conservation of hydrographic basins, together with the recognition of vegetation cover as a fundamental element for the maintenance of water resources and the integrity of the ecosystem (Tambosi, et al., 2015; Wurtzebach, & Schultz, 2016), although it is a very important premise for environmental conservation, they present many difficulties. the precept of conservation is explicit in the Forest Code, as one of the principles of sustainable development: "Brazil's commitment to the preservation of its forests and other forms of native vegetation, as well as biodiversity, soil, water resources and the integrity of the climate system, for the well-being of present and future generations" (art. 1, item I of Law No. 12651, 2012). However, the challenge for its management is still great.

In the Iguaçu River basin fragmentation is high (Hentz, et al., 2015). Mapping by MapBiomas (Projeto de Mapeamento Anual do Uso e Cobertura da Terra no Brasil [MapBiomas], 2016) shows a reduction of 2.94% of vegetation cover between the years 2010 and 2020. Conservation in the face of economic pressures of land use and occupation by agricultural activities, urbanization, and others, stimulates the improvement of management tools.

The use and occupation of the Monteiro and Sarandi River sub-basins with the agricultural (31.3%) and pasture (28.5%) classes, add up to about 60% of the area (Table 2). These data contrast with the conservation of the Floriano River. They also make explicit the importance of agropastoral activities. In these basins the vegetation occupied less than 19% of the area and the urban class about 5.6% (Table 1; Figures 2, 3A and 3B).

The agropastoral activities are favored by flat or undulated slopes, which represent about 30% of the area (Silva et al., 2022), and that according to Pinheiro et al. (2011), must have fertile soil, be arable and drained. Celestino et al. (2019) categorized the two basins as medium fragility, indicating that agropastoral activities, urban centers, especially Capitão Leônidas Marques and Realeza, with the highest densities in the region (Brazilian Institute of Geography and Statistics [IBGE], 2014), should be monitored. Vegetation areas must be conserved, mainly with a view to conserving the region's water resources.
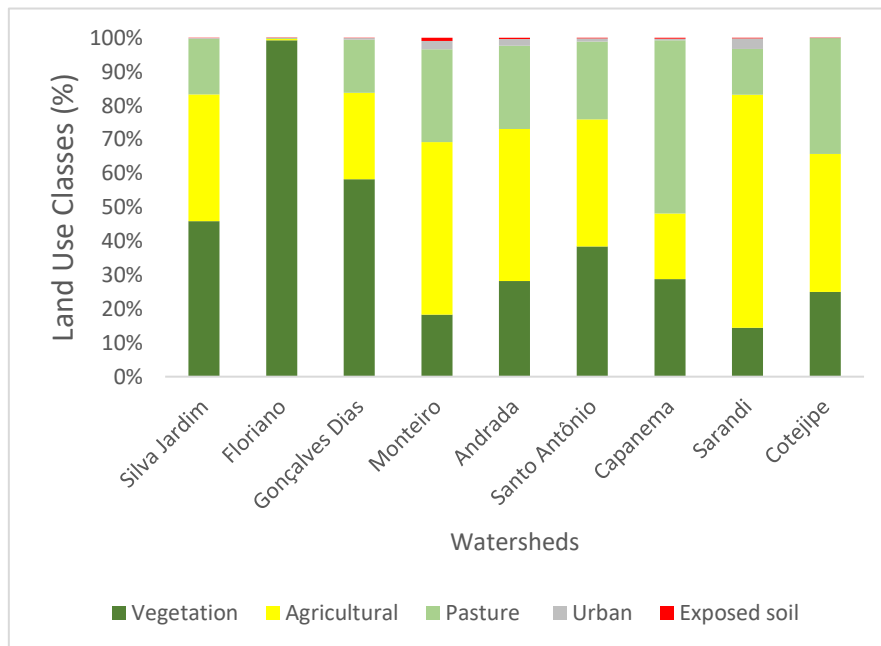
The vegetation class, in the sub-basins of the Andrada, Santo Antonio, Cotejipe and Capanema Rivers, has an intermediate situation, occupying between 25 and 38%. And the agropastoral activities (agriculture and pasture) are between 60 and 74% (Table 2; Figures 2, 3A and 3B). In Capanema River sub-basin the pasture class occupied more than half of the basin (51.17%), it is associated with the presence of high slopes (Table 2, Figures 2 and 3B), with a predominance of strong undulating and mountainous relief (Silva et al., 2022). The urban class, in Andrada River sub-basin, was relatively higher, in it there are several municipalities in its territory and surroundings (Table 2; Figures 2 and 3A).

Table 2: Areas of land use and occupation classes in hectares for nine tributary watersheds of the Lower Iguaçu River basin and Kappa statistics results.

Watershed / area (ha)	Urban	Exposed soil	Vegetation	Pasture	Agricultural	Total	Kappa statistics
Silva Jardim	68.57	48.56	26283.29	9459.19	21413.40	**57273.01**	0.997
Floriano	58.62	0.17	67187.60	157.53	251.67	**67655.59**	1.000
Gonçalves Dias	245.14	13.93	28826.68	7775.68	12572.37	**49433.80**	0.999
Monteiro	275.94	106.80	2075.79	3107.12	5773.43	**11339.08**	0.994
Andrada	2839.16	405.93	39472.28	34449.66	62883.48	**140050.51**	0.996
Santo Antônio	1193.94	181.08	49153.92	29451.95	47944.57	**127925.46**	0.996
Capanema	880.03	456.32	56582.76	100664.02	38155.33	**196738.46**	0.998
Sarandi	731.34	22.65	3300.29	3066.94	15713.22	**22834.44**	0.996
Cotejipe	32.67	28.54	15889.50	21701.12	25809.91	**63461.74**	0.997
Total (ha)	**6325.41**	**1263.98**	**288772.11**	**209833.21**	**230517.38**	**736712.09**	
Total (%)	**0.86**	**0.17**	**39.20**	**28.48**	**31.29**	**100**	

Source: Authors.

Figure 2: Percentage of land use and occupation classes in seven river sub- basins of the Lower Iguaçu River basin.
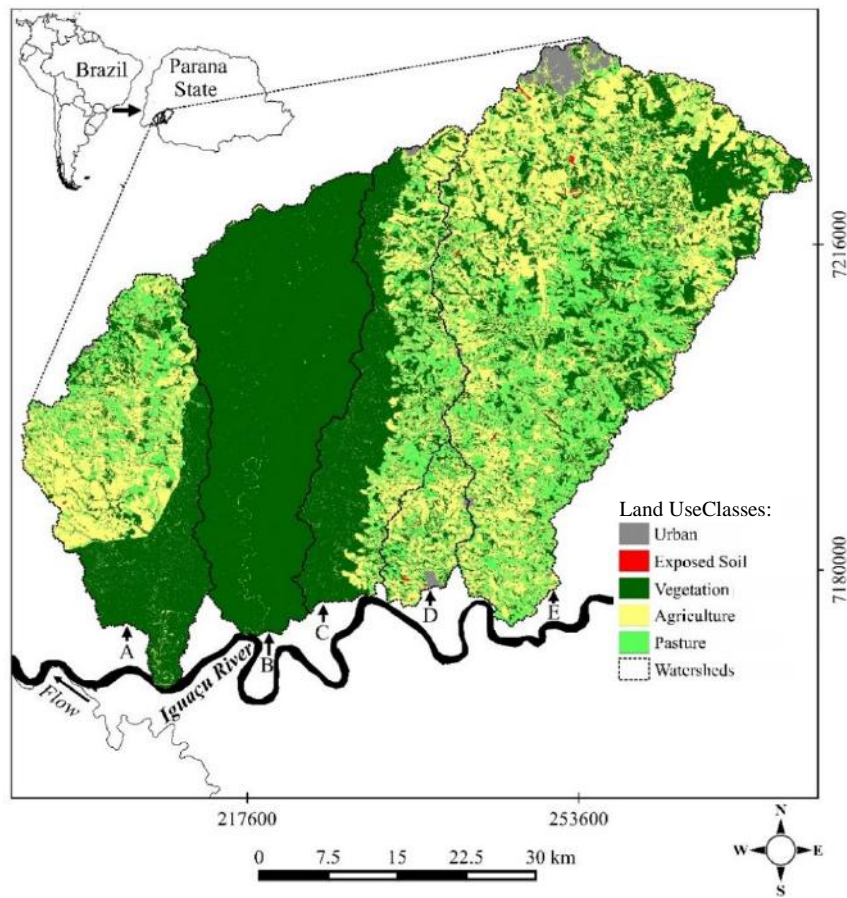

Source: Authors.

The Kappa coefficient values varied among the sub-basins (Table 2), indicating a good accuracy for the classes formed (from 99.4 to 99.9%), according to Landis e Koch (1977). These values were higher than those obtained by Yuan, et al., (2005), but the classes and the type of image used by them were different.
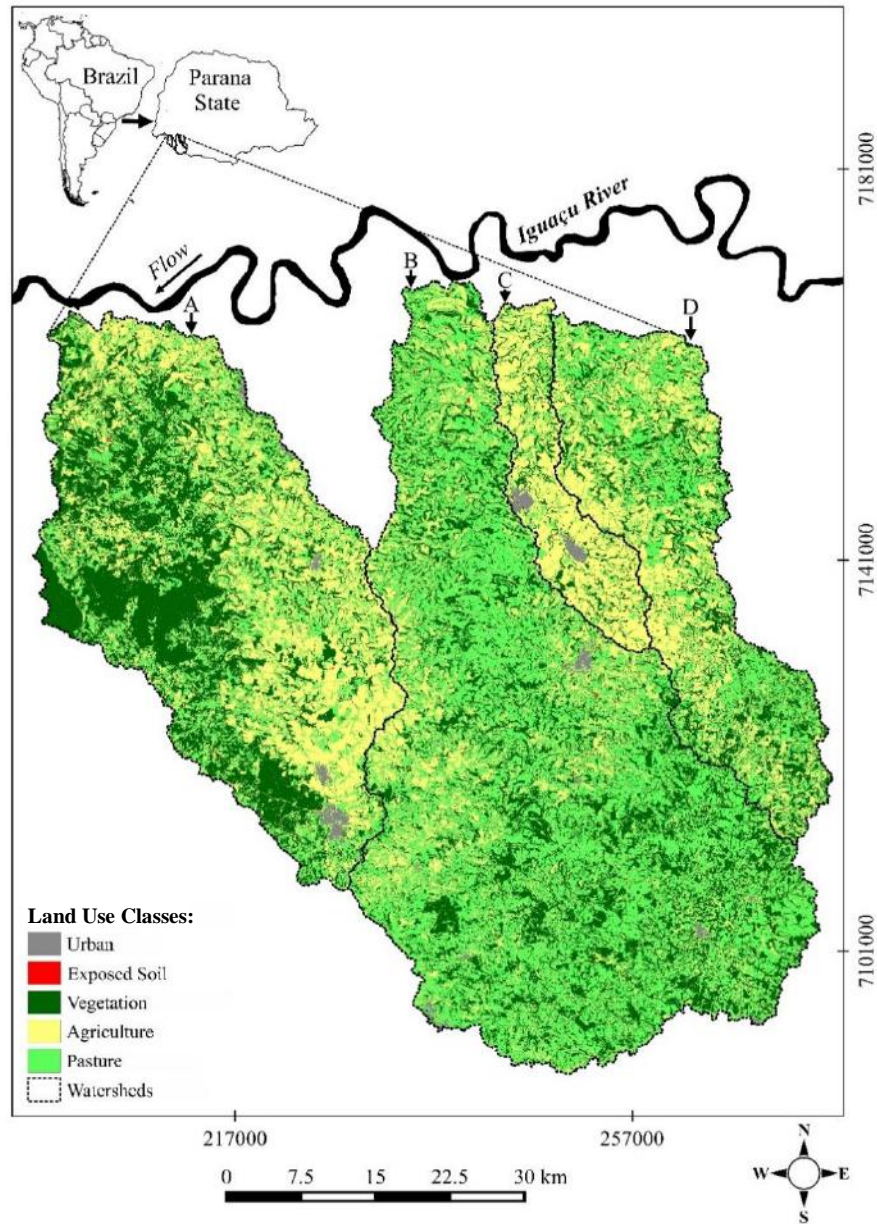
The initial challenge for the classification of the images, obtained by the Sentinel-2 satellite, were some areas that have similar wavelengths, mainly in the green scale, making it difficult to separate the agricultural and pasture classes, due to the similarity of the reflected wavelengths. vegetation and captured by the sensor. This challenge was overcome by selecting these areas in advance, at the time of analysis, and changing the wavelength values further apart between the classes. In this way, precision was increased in separating land use classes. However, the information extraction period for image creation is an important factor.

Figure 3A: Land use classes in the sub-basins located at right bank of the Lower Iguaçu River. The letters indicate the river sub-basins: A, Silva Jardim; B, Floriano; C, Gonçalves Dias; D, Monteiro; and E, Andrada.

Source: Authors.

Figure 3B: Land use classes in the sub-basins located at left bank of the Lower Iguaçu River. The letters indicate the basins - A, Santo Antônio; B, Capanema; C, Sarandi; and D, Cotejipe.
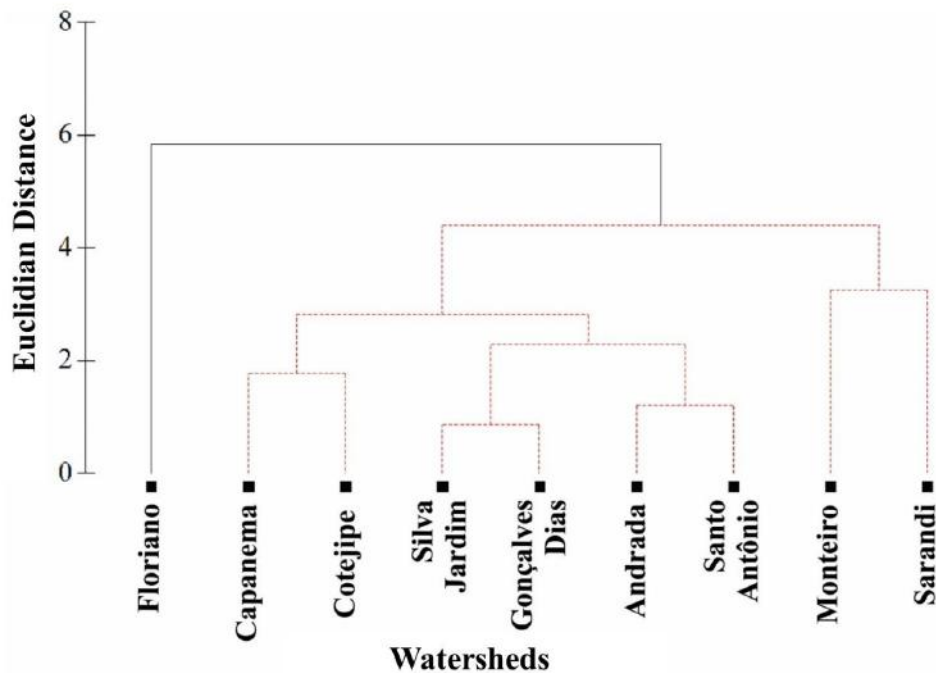

Source: Authors.

In the cluster analysis, five groups were observed (Figure 4). The Floriano River basin distinguished itself from the others according to the SIMPROF test, being practically all occupied with native vegetation (Table 2; Figures 2 and 3A). From the Floriano River, it was possible to verify the groups with the most conserved vegetation areas and their replacement by agricultural, pasture or urban areas.

The group with the best degree of vegetation conservation was composed of the basins of the rivers Silva Jardim and Gonçalves Dias, followed by Andrada and Santo Antônio, Capanema and Cotejipe and finally Monteiro and Sarandi. The latter, in turn, had the lowest degree of vegetation cover. The tendency of hydrographic basins to environmental degradation can be evaluated using as main criterion the preserved vegetation, which varied a lot among the analyzed basins. The absence of

vegetation, replaced by other activities, can weaken water systems, increasing other impacts, such as water erosion on the banks and silting of rivers.

Figure 4: Similarity dendrogram (Cluster analysis and SIMPROF) from data matrix transformed by river sub-basins. Significant groups ($p < 0.05$) showed in red lines, and ungrouped river sub-basin in black.

Source: Authors.

We can infer that the Floriano river sub-basin is the most preserved, followed by Silva Jardim and Gonçalves Dias. The Capanema, Cotejipe, Andrada and Santo Antônio River sub-basins possess comparatively an intermediate degree of environmental preservation and the Monteiro and Sarandi sub-basins exhibit the least degree of environmental preservation, with the greatest distance between them.

4. Conclusions

The supervised multispectral classification used in our study obtained satisfactory results. The grouping showed that the most conserved sub-basins are the Floriano, Silva Jardim and Gonçalves Dias Rivers. The most susceptible to degradation are the basins of the Monteiro and Sarandi Rivers.

Besides the characterization of the sub-basins, this description, which is unprecedented, provides as a baseline for planning, monitoring and management of the area. It also serves for environmental modeling, conservation of water resources, biodiversity, and environmental services.

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