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Time series analysis of land use and occupation in permanent preservation areas of the Paraíba River Basin

Análise das séries temporais de uso e ocupação da terra em Áreas de Preservação Permanente (APP) da Bacia do Rio Paraíba

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Abstract

Any alteration caused in riparian areas of hydrographic basins directly causes changes in the dynamics of rivers, lakes, and urban areas with the elements of energy flow, dissolved material and sediments. Better planning, management and protection of natural resources in the areas of a river basin require knowledge of the characteristics of water courses, vegetation and land use and occupation. The present work aimed to analyze a time series of land use and occupation data in Permanent Preservation Areas (PPAs) of the Paraíba River Basin according to the precepts of the Brazilian Forest Code and with the aid of geoprocessing tools and the Pettitt test and Mann-Kendall test statistics. The Pettitt test showed a temporal change in the average natural cover starting in 2007, with an increase of 4.2%. Based on the Mann-Kendall test, there was a downward trend in the cover of riparian forests in 36.72% of the PPAs, prevailing over PPAs with upward trends, in the period from 1985 to 2006, demonstrating greater degradation of riparian forest areas during this period, mainly in the Middle and Lower Paraíba River regions. For the period from 2006 to 2020, there was a significant change in areas with upward trends in land with natural cover (28.31%), with an increase of 12.5% compared to the previous period.

Keywords:
Riparian forests, Pettitt test, Mann-Kendall test, Forest code.

Resumo

É imprescindível entender que qualquer alteração causada nas áreas ciliares das bacias hidrográficas provoca mudanças diretamente na dinâmica dos rios, lagos, áreas urbanas com os elementos de fluxo de energia, material dissolvido e sedimentos. Assim, para melhor

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planejamento, gestão e proteção dos recursos naturais existentes nas áreas de uma bacia hidrográfica, faz-se necessário conhecer as características dos cursos d'água, vegetação e uso e ocupação da terra. O presente trabalho tem como objetivo analisar a série temporal dos dados de uso e ocupação da terra em Áreas de Preservação Permanente (APP) na Bacia Hidrográfica do Rio Paraíba, segundo os preceitos do Código Florestal brasileiro e com auxílio das ferramentas de geoprocessamento e das metodologias estatísticas do Teste de Pettitt e Teste de Mann-Kendall. O teste Pettitt apresentou uma mudança temporal na média de cobertura natural a partir do ano de 2007, com aumento de 4,2%. A partir do teste de Mann-Kendall, notou-se que houve tendência de decrescimento das matas ciliares em 36,72% das APPs analisadas, superior à área que apresentou crescimento, demonstrando maior degradação das matas ciliares no período de 1985 a 2006, principalmente nas regiões do Médio e Baixo Curso do Rio Paraíba. Para o período de 2006 a 2020, há mudança significativa nas áreas com tendência de crescimento de coberturas naturais (28,31%), incremento de 12,5% se comparado ao período anterior.

Palavras-chave:
Matas ciliares, Teste de Pettitt, Teste de Mann-Kendall, Código florestal.

I. INTRODUCTION

Hydrographic basins need to be viewed as units for environmental planning and management, and their environmental attributes need to be analyzed (LOPES, 2018). Optimized planning and management and the protection of the natural resources existing in these units requires knowledge of the characteristics of watercourses, climate, relief, precipitation regime, vegetation, and land use and occupation.

When poorly planned and not properly supervised, anthropogenic occupation and its associated activities can compromise the natural resources in river basins. It has been demonstrated that the adoption of inadequate techniques in agricultural activities can cause impacts such as degradation of the water quality of water bodies, contamination of the soil, and deforestation of riparian forests.

Riparian forests play an important role in river basins, as they are responsible for reducing erosion and the velocity of flood waters, recharging groundwater, reducing water pollution by retaining sediments and filtering fertilizers and pesticides, increasing (terrestrial and aquatic) plant and animal biodiversity, among others (SILVA; NOBRE; CASTRO, 2019). It is essential to understand that any change caused in the riparian areas of a river basin directly affects the dynamics of rivers, lakes, urban areas in terms of energy flow, dissolved material and sediments.

According to Federal Law number 12,651 of May 25, 2012, which establishes the Forest Code, riparian forests can be defined as "protected areas, covered or not by native vegetation, with the environmental

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function of preserving water resources, landscape, geological stability and biodiversity, facilitating the gene flow of fauna and flora, protecting the soil, and guaranteeing the well-being of human populations".

Irregular land use and occupation can generate environmental problems, leading to deforestation of native vegetation, loss of biodiversity, and degradation of the ecosystem. The absence of vegetation can increase soil erosion and cause problems such as siltation of rivers and streams, compromising water quality and increasing the likelihood of natural disasters. The negative impacts caused by irregular land use and occupation can be reduced through the promotion and implementation of Permanent Preservation Areas (PPAs) (LIMA; SANTANA; REIS, 2022; BRASIL, 2012).

The proper characterization and monitoring of elements of a river basin, such as riparian forests, is important. A Geographic Information System (GIS), which expands the rapid and accurate collection of data and information, can be useful in the analysis of riparian forests. Currently, GIS represent a useful tool for planning management actions in river basins, and remote sensing has several applications, including the temporal monitoring of vegetation cover.

Statistical tools are is also a strong ally of GIS technologies, as they can assist in several ways in the analysis of temporal data. A time series consists of a set of observations ordered in time whose analysis makes it possible to describe the behavior of the series and detect trends, cycles and seasonal variations. They are widely applied in studies of climate change, precipitation change, flow trends in water bodies, monitoring of water quality, and analysis of the temporal behavior of wind speed, temperature, among others.

This study aims to analyze a time series of land use and occupation data in PPAs of the Paraíba River Basin, the second largest basin in the state of Paraíba, where livestock and agriculture are the main economic activities. The analysis was carried out based on the principles of the Brazilian Forest Code and with the aid of geoprocessing tools and the statistical methodologies of the Pettitt test and Mann-Kendall test.

This study is relevant for the situational diagnosis of PPAs regarding the land use and occupation of the study area and can support government actions in the preservation of PPAs, as well as direct decision-making at the river basin level.

II. Material and Methods

In order to achieve the proposed objective, the study followed the four methodological steps presented in Figure 1 and detailed under this topic.

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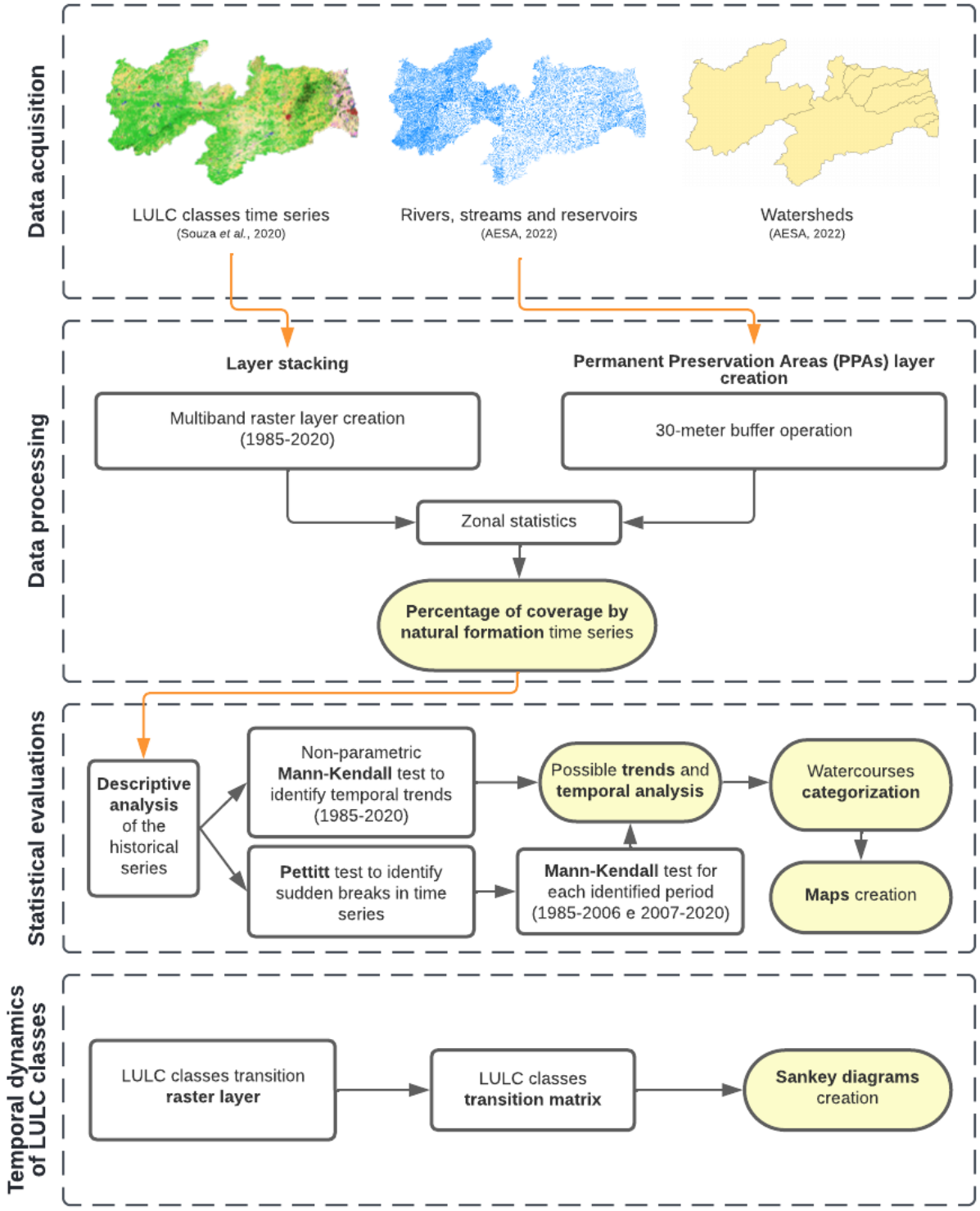

Figure 1 – Methodological flowchart. Source: The author (2022).

Characterization of the study area

The Paraíba River Basin is the second largest basin in the state of Paraíba and has a population density of 91.08 inhabitants/km². It has an area of 20,071.83 km², covering 38.0% of the state's territory and is home

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to 1,828,178 inhabitants, which correspond to 52% of the total population of Paraíba. Eighty five municipalities are located in the basin, in whole or in part, including João Pessoa, the capital, and Campina Grande, the second largest urban center in the state (CBH-PB, 2022).

This is considered one of the largest basins in the northeastern semi-arid region of Brazil and, as shown in the map of Figure 2, is composed of the Taperoá River sub-basin, and the Upper, Middle and Lower Paraíba River regions. In addition to the Paraíba River, the Taperoá River, Boa Vista River, and Umbuzeiro River are also within this unit. The main reservoirs are Epitácio Pessoa and Acauã, mainly used for water supply to humans. It is important to mention that, as shown in Figure 2, the East Axis of the Transposition of the São Francisco River contributes to the regularization of the flow of the Paraíba River.

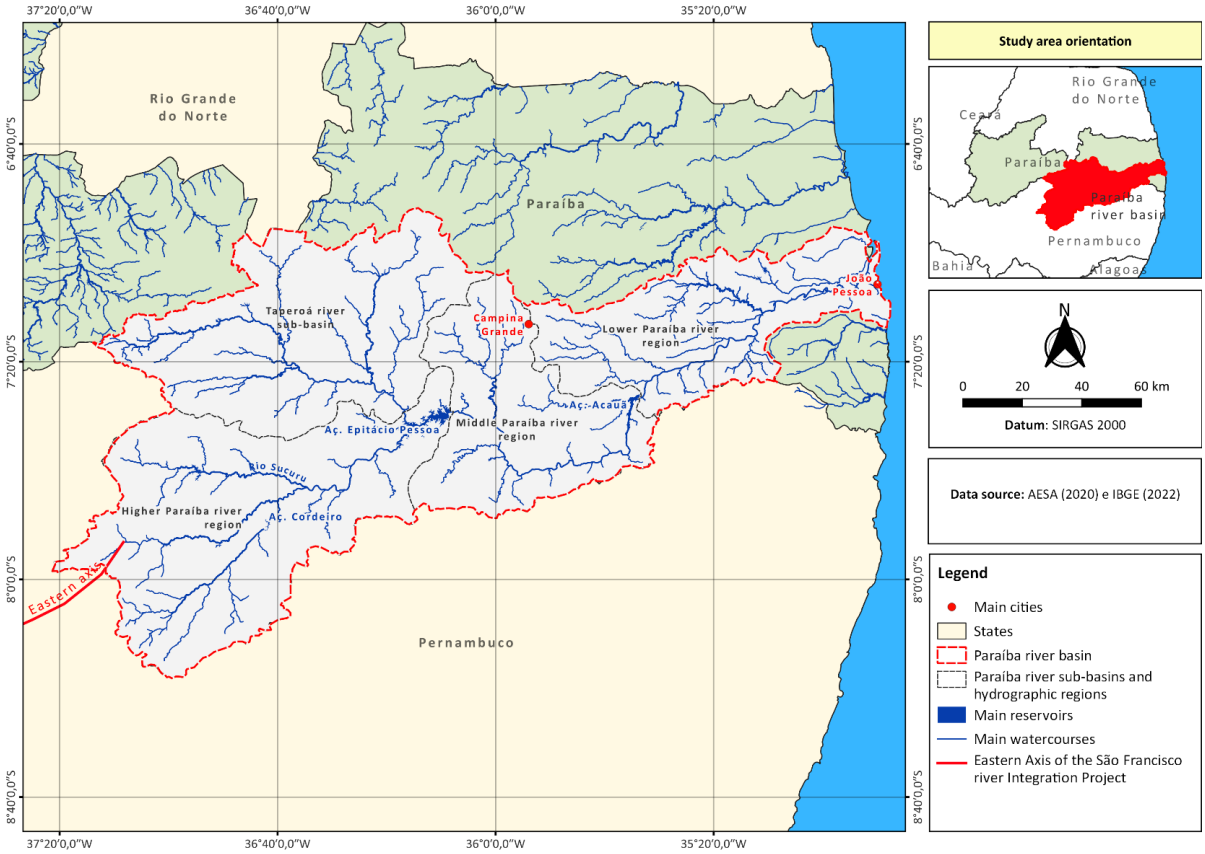

Figure 2 – Paraíba River Hydrographic Basin. Source: The author (2022).

According to data from EFSA (2022), the Caatinga and the Atlantic Forest are the biomes that occur in the Paraíba River Basin, occupying 92.0% and 8.0% of its area, respectively. The climate of the region is tropical dry, according to the Strahler classification, and has irregular rainfall with precipitation between 250

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and 1700 mm. The main uses of water in the Paraíba River Basin are public supply for human and animal consumption, fishing, irrigation, and leisure.

The Paraíba River Basin is of great importance for the agricultural sector and, consequently, for local and regional socioeconomic development. The region is characterized by livestock and agriculture activities, resulting in the vulnerability of natural resources. The main conflicts, indicated by the Paraíba River Basin Committee (CBH-PB) (2022), are water contamination, depletion of soil productive capacity, widespread erosion, water shortage, and degradation of riparian forests.

Data acquisition

Land use and land cover data from the collection 6 published by the MapBiomas (2021) platform were used for the time series of land use and occupation of PPAs on the banks of watercourses. The platform is accessed through the Google Earth Engine and provides several catalogs of satellite images together with a set of geospatial data that allow planetary-scale analyses.

The Annual Land Use and Land Cover Mapping of Brazil (MapBiomas) project is an initiative of the Climate Observatory, supported by a network of institutions involving universities, non-governmental organizations and technology companies with the purpose of annually mapping Brazil's land use and land cover and monitoring the changes in the territory. This mapping allows a historical analysis of the dynamics and evolution of and use and occupation throughout the national territory (MapBiomas, 2022).

The data published in MapBiomas (2022) present 25 classes of land use and land cover divided into six categories: Forest; Non-forest natural formation; Agriculture; Non-vegetated area; Water bodies; and, not observed. It should be noted that the Forest and Non-forest natural formation categories are considered natural covers. The entire historical series of matrix data from MapBiomas collection 6 (1985 – 2020) was used in this study. This collection has a 30-m spatial resolution and is produced from the classification of Landsat-8 satellite images by the Random Forest algorithm, as observed in Figure 3.

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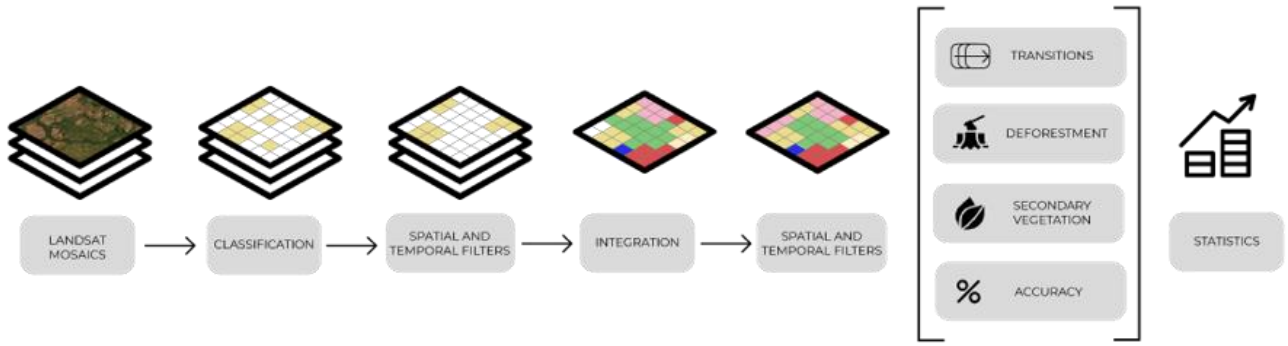

Figure 3 – Methodological procedure for satellite image classification in MapBiomas. Source: MapBiomas (2021).

Data on hydrographic basins, reservoirs, rivers and streams in the state were also used in the processing of data to create maps. These data were acquired through databases of the National Water and Basic Sanitation Agency (ANA, 2022) and the Executive Agency for Water Management of the State of Paraíba (AESA, 2022).

Data processing

After the necessary data were acquired, they were processed in order to delimit the study area and transform them into a format compatible with the statistical software. GIS operations in QGIS 3.22 and the functions available in spreadsheet software such as Microsoft Excel were used to process the data.

According to the Forest Code established by Law number 12.651/12 (BRASIL, 2012), strips on the banks of rivers and streams are considered PPAs and their extension, ranging from 30 to 500 meters in each side, must be determined based on the width of the water body. Due to the lack of georeferenced data from PPAs of the Paraíba River Basin, these areas were generated from the shapefiles of accumulation reservoirs, rivers and streams located within the limits of the hydrographic basin.

The buffer operation available in GIS was used to create the 30-meter PPA strips in the basin. Considering that most of the rivers analyzed are classified as intermittent rivers or have a regular bed less than 10 meters wide, the central axis of the rivers and streams was used as a reference for the buffer. It is important to note that the determination of PPAs from the central axis of the courses does not influence the statistical analyses because the pixel size of the raster data available in MapBiomas is larger than the largest regular bed found in the basin studied.

To simplify the subsequent manipulation, the matrix data obtained from the MapBiomas platform were stacked in a single multiband raster layer, in which each band represented the land use and land cover classification per year of the historical series (1985-2020), using the function of creation of virtual rasters.

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Finally, the generated layers were submitted to the Zonal Statistics function to perform a cutout of the land use matrix data for the study area, quantifying the number of cells of each of the land use classes monitored by MapBiomas within the PPAs. The result of the process was exported in spreadsheet format and then the percentage of land covered by natural formations, considering the categories Forest and Non-forest natural formation, was calculated for each of the watercourse stretches.

Statistical analyses

A descriptive analysis of the historical series of land covered by natural formations in the PPAs obtained in the previous step was initially carried out. A descriptive analysis is the first manipulation performed in quantitative studies of time series and has as one of the main objectives to understand the historical series through graphs and tables that summarize the behavior of the data. In this study, this step was performed using the XLSTAT 2022 software.

The time trend of the historical series of land covered by natural formations was evaluated by the non-parametric Mann-Kendall test (MK), considering a significance level of 5%. Proposed by Mann (1945) and modified by Kendall (1975), the Mann-Kendall test compares each data value of a time series with subsequent values over time, and computes the number of times in which the subsequent terms are greater than the term being analyzed, resulting in the S statistic.

The RStudio statistical software, which allows batch processing, was used to perform the Mann-Kendall test, since there was a large number of watercourse stretches analyzed. At first, the test was performed for the entire historical series obtained from MapBiomas collection 6 (1985-2020). However, because a long period of 36 years is covered in this collection, we sought to analyze the occurrence of data trend changes within the observed interval.

The Pettitt test (Pettit, 1979) is used to investigate the existence of sudden breaks in time series caused by trend changes in the analyzed period. With the application of this test, it is possible to indicate whether samples from the same time series belong to the same population and identify the point where the time break occurs. The identification of this breakpoint is fundamental for time trend analyses in fractions of the historical series and directly influences the results obtained and the discussion of the analyzed problem. The Pettitt test was applied in this study using the XLSTAT 2022 software, adopting a significance level of 5%.

Based on the results of the Pettitt test, the historical series was divided into two periods separated by the breakpoint in the time trend of the data. The Mann-Kendall test was applied using RStudio. The statistics

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generated in this test were exported to Microsoft Excel and then the data for the 2,304 stretches of PPAs were interpreted automatically, according to the hypotheses and categories of time trends presented in Box 1.

In order to incorporate the spatial component in the statistical analyses and facilitate the visualization of the results obtained in the territory, time trend maps were prepared for the three periods presented. For the production of these maps in QGIS, the trend categories obtained in each of the sections were related to the vector layer of PPAs, through the conjunction of information present in the data sheet.

Box 1 – Test hypotheses and time trend categories

Hypotheses	p-value	S statistic	Trend categories
There is no statistically significant time trend	> 0.05	-	There is no time trend
There is a statistically significant time trend	< 0.05	> 0	Upward trend
		< 0	Downward trend

Source: The author (2022).

Analysis of temporal dynamics of land use and occupation

The temporal dynamics of the land cover classes of the study area were analyzed in order to identify the anthropic activities with greater influence on class changes observed within the analyzed periods. For this purpose, matrix layers of land use and land cover class transitions were created for the two periods (1985-2006 and 2007-2020).

The pixel values of the initial and final years of the periods were summed using the raster calculator tool of QGIS 3.22 so that the first two and last two digits of the resulting layer represented the land use and land cover classes in the initial and final years of the analyzed period, respectively. Then, a histogram of the transition data was prepared and exported into an Excel spreadsheet, making it possible to produce a transition matrix to identify the flows between the land use and land cover classes during the analyzed period. The flows were presented through Sankey Diagrams, which are indicated to facilitate their visualization.

III. RESULTS AND DISCUSSION

Annual data on land covered by natural formations in the PPAs of the Paraíba River Basin, corresponding to the categories Forest and Non-forest natural formations, were descriptively analyzed. Low variation was found, indicated by a symmetric distribution of the data, with the mean and median showing a difference of only 0.2% and amplitude of 14.7%, as shown in the boxplot presented in Figure 4.

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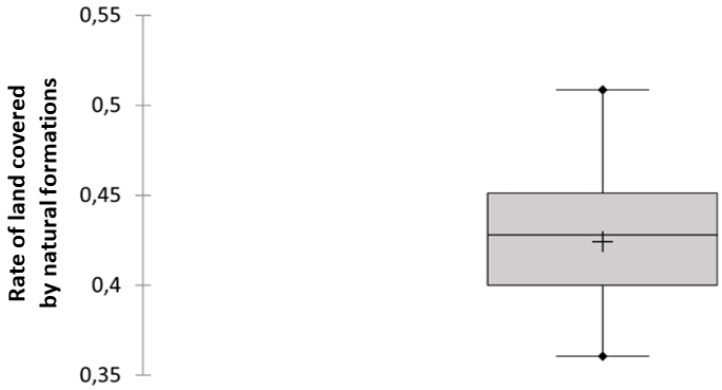

Figure 4 – Boxplot of the historical series of land covered by natural formations in Permanent Preservation Areas (PPAs) of the Paraíba River Basin.
Source: The author (2022).

The maximum percentage of cover, 50.8%, was observed in 2019, and the minimum, 36.1%, in 1998. The interquartile range for the data series studied was 5.1%. The variance of the data in the historical series was 0.1% and the standard deviation was 3.7%, demonstrating that the values were agglomerated, close to each other. Therefore, the the Mann-Kendall was performed for the studied time series in each of the 2,304 river stretches and the results were spatialized and presented in the map of Figure 5.

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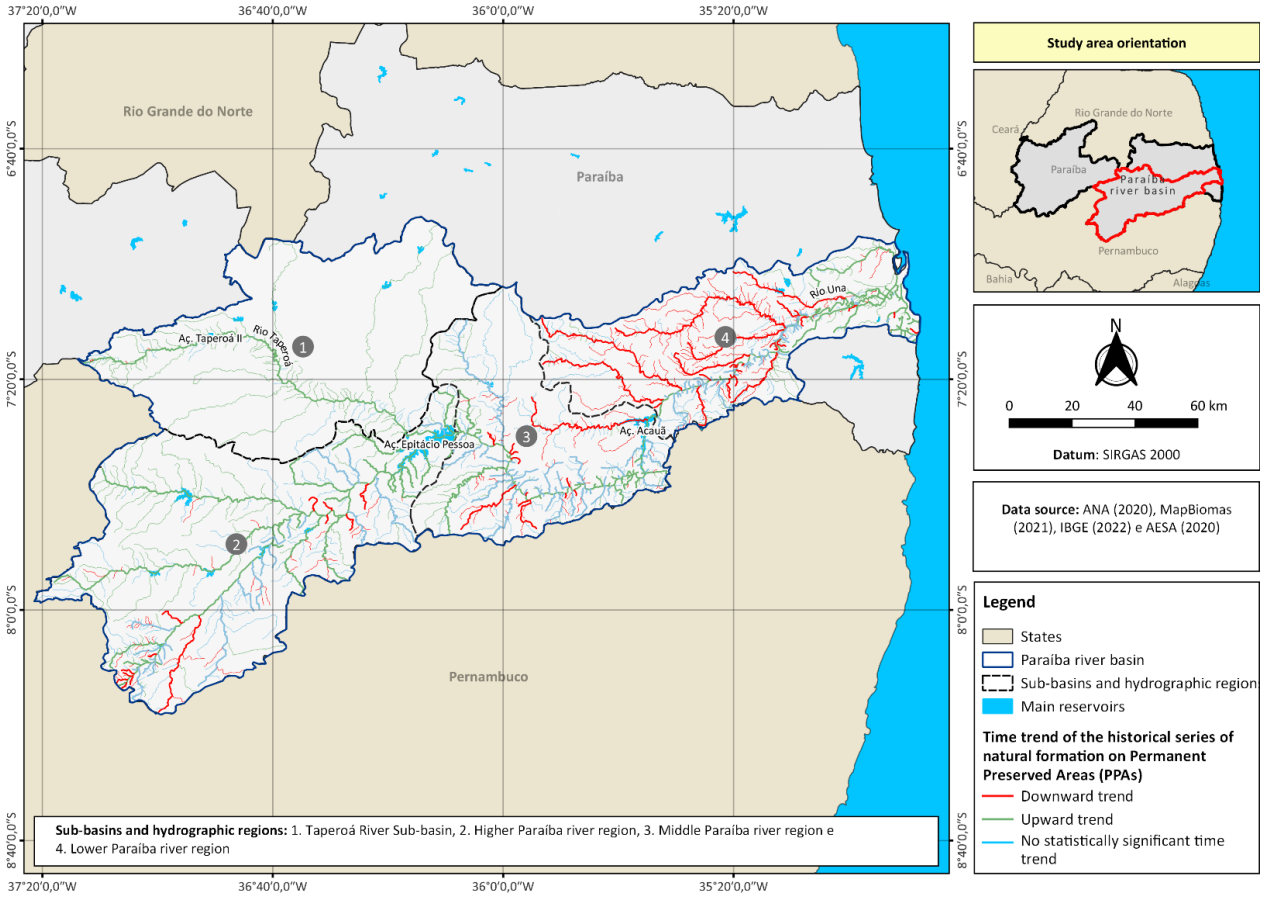

Figure 5 – Trend map of land covered by natural formations in Permanent Preservation Areas (PPAs) of the Paraíba River Basin – 1985 to 2020. Source: The author (2022).

The map shows an upward trend (p-value < 0.05 and S statistic > 0) in 44.05% of the PPAs analyzed and a downward trend (p-value < 0.05 and S statistic < 0) in only 21.53%, mainly concentrated in the Lower Paraíba River Region. Moraes *et al*. (2021) indicate that the environmental degradation in the PPAs of the Paraíba River in the municipality of Itabaiana/PB results from lack of inspection by public agencies and lack of awareness of the population, which not only occupies these areas improperly, but also exploits it sometimes inappropriately for profit.

Showed a temporal change in the average natural cover from 2007 onwards, with an increase of 4.2% in the average for the years 2007-2020 (45.0%) in relation to 1985-2006. The breakpoint in the data indicates that the Mann-Kendall test is more representative when the series for the two periods presented are analyzed.

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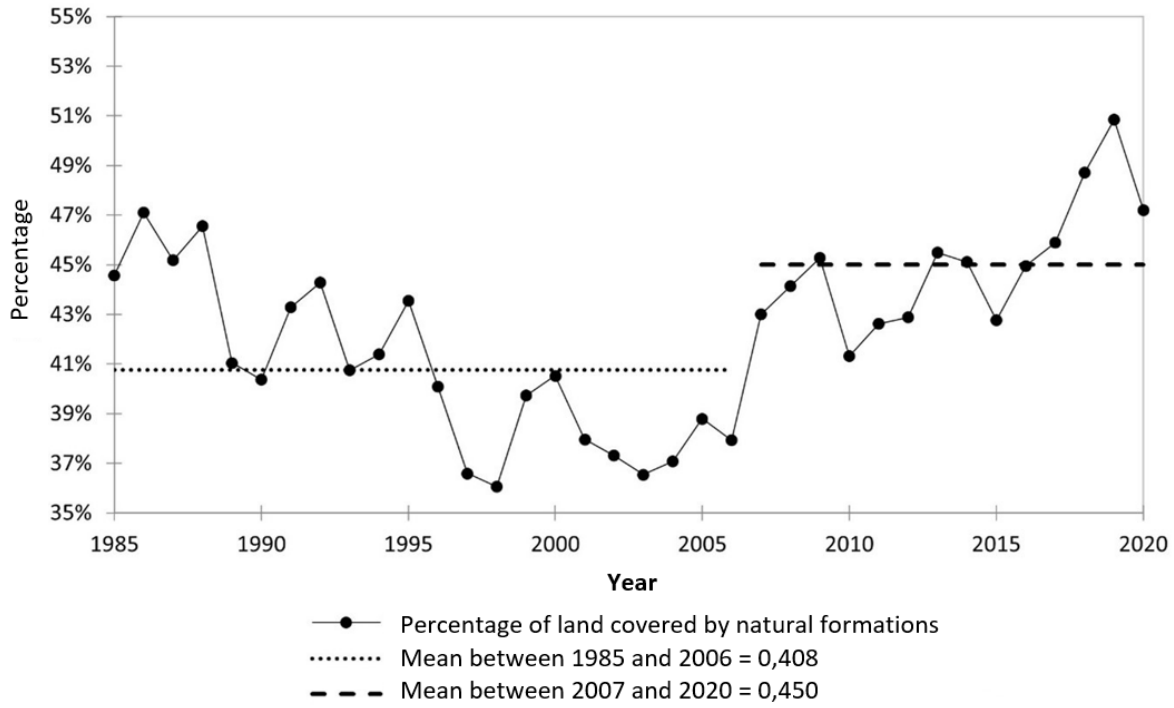

Figure 6 – Result of the Pettitt test for the time series of percentage of land covered by natural formations in Permanent Preservation Areas (PPAs) of the Paraíba River Basin. Source: The author (2022).

This change in the time series occurred in the year when the CBH-PB was created through Decree number 27.560 of September 4, 2006. The Article 3 of the Internal Regime of the CBH-PB (2011) defines the purposes of the Committee and include, in paragraphs VI and IX, the conformation of the management of water resources, prioritizing the preservation and conservation of the environment, including riparian forests in the study area, as well as the stimulation and proposal of protection and preservation of water resources and the environment against actions that may compromise current and future multiple use.

Carmo Jr. (2021) analyzes the actions of the CBH-PB, based on the committee's collegiate meetings from 2007 to 2020, and one of the topics addressed in the meetings during this period was related to environmental degradation on the banks of the Paraíba River caused by anthropic actions. Such attention given to riparian forest areas is in line with the upward trend observed in the present study, in Figure 6, especially in the period from 2015 to 2019, with a recovery of 8.1% of areas covered by natural formations in the river basin.

At the same time, the approval at the national congress of the transposition of the São Francisco River directly influenced the preservation of PPAs because the Environmental Impact Assessment and the Environmental Impact Report – EIA/RIMA (2004) provide for the recovery and preservation of riparian forests

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through the Program for the Revitalization of degraded areas and, also, the incentive for the conservation and valorization of the Caatinga through the Environmental Education Program that aims to raise the awareness of the population regarding actions to preserve these areas. It is noteworthy that the restoration of riparian forests and basic sanitation in the areas of hydrographic basins are a priority in the Hydrographic Basin Integration Projects (PIBHI).

After the Pettitt test, in order to understand the statistical behavior of the periods from 1985-2006 and 2007-2020, the Mann-Kendall test was again performed to analyze the possibility of statistically significant upward or downward trends in areas with natural formations in the PPAs of the Paraíba River Basin, which were spatialized in maps (Figure 7 and Figure 8). Using the Mann-Kendall statistical test, França *et al*. (2021) found a reduction of areas with natural cover in the São Francisco River Basin from 2001 to 2013, with relevant transitions of the type "Forest into Pasture", "Wooded Savannah into Pasture", and "Agricultural Lands into Pasture".

The map in Figure 7 shows the time trend of areas covered with natural formations from 1985 to 2006 in the PPAs of the water bodies in the Paraíba River Basin, dividing them into sub-basins and regions. Land covered by riparian forests had an upward trend in the PPAs in only 16.65% of the entire area of the basin during the the studied period; such areas, represented in green in the map, are mostly concentrated in the Taperoá River sub-basin, which has a lower drainage density than the other regions. Lima (2017) states that the urban area and the demographic density in the Taperoá River sub-basin are not related with vegetation cover, suggesting a low interference of anthropic actions in native forests.

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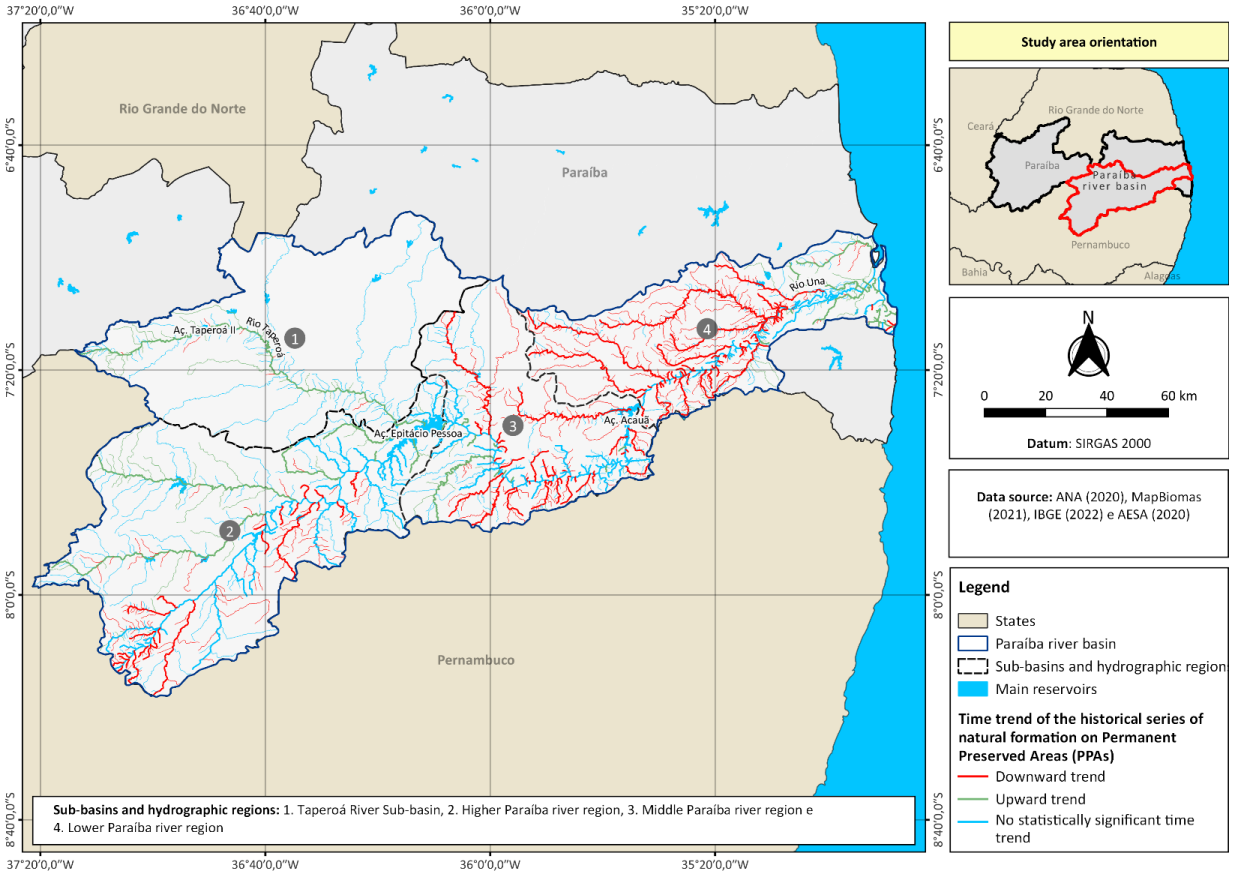

Figure 7 – Trend map of the land covered by natural formations in Permanent Preservation Areas (PPAs) of the Paraíba River Basin – 1985 to 2006. Source: The author (2022).

Areas without statistically significant trends (p-value > 0.05) represented 46.63% of the total area of the river basin, and they were mostly concentrated in the Upper Paraíba River Region. In turn, 36.72% of the PPAs presented downward trends, and thus a small portion had upward trends, indicating the predominance of degradation of riparian forests in the period from 1985 to 2006, especially in the Middle and Lower Paraíba River Regions, where the municipalities of Campina Grande and João Pessoa, with higher demographic density, are located.

The trend map created for the period from 2007 to 2020 (Figure 8) showed a significant change, with an upward trend (28.31 %) of areas with natural formations, with an increase of 12.5% compared to the previous period. There was also a 20% reduction of areas with downward trends (28.31%) compared to the period from 1985 to 2006.

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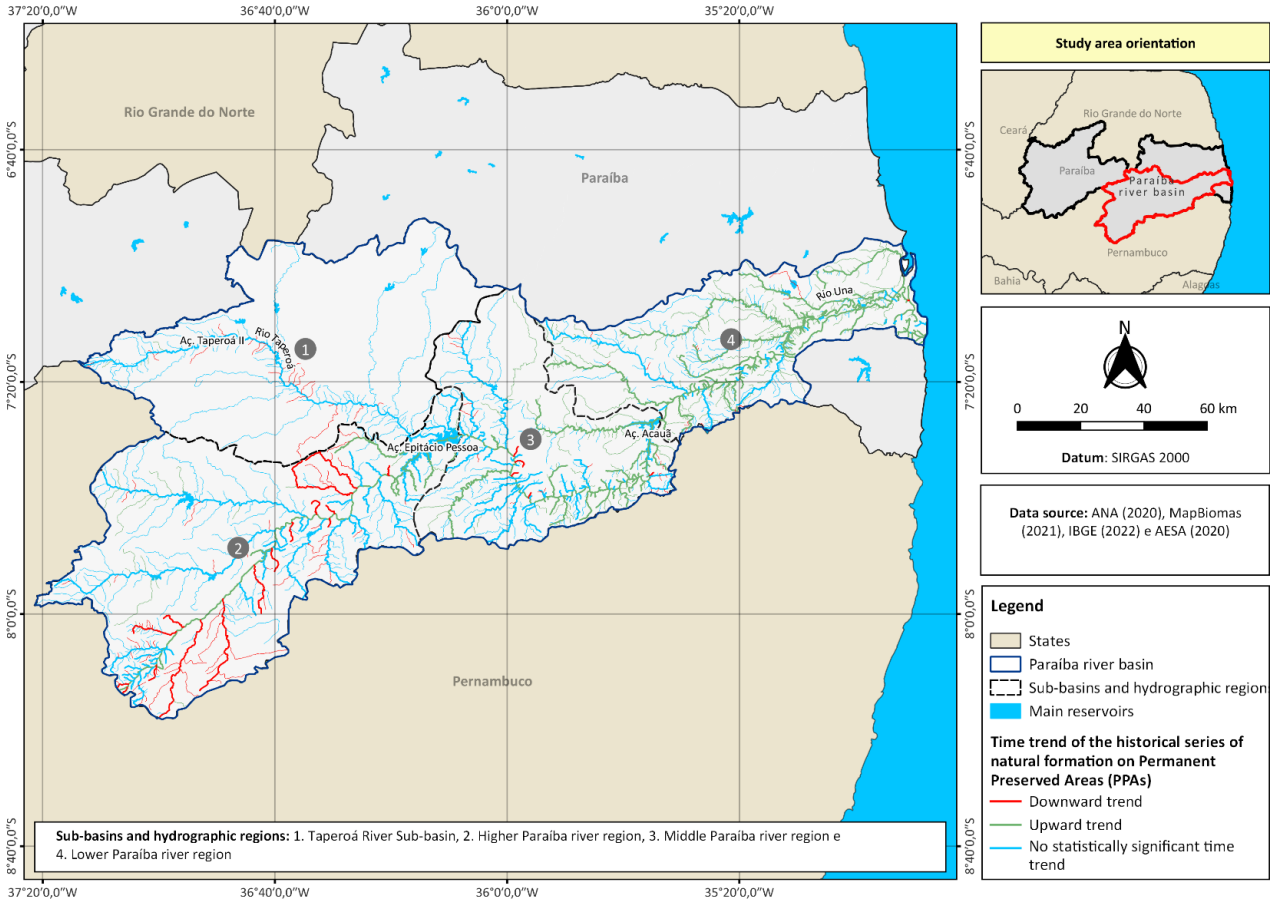

Figure 8 – Trend map of the land covered by natural formations in the Permanent Preservation Areas (PPAs) of the Paraíba River Basin – 2007 to 2020. Source: The author (2022).

The most notorious changes observed between the two periods studied, shown in the map in Figure 8, occurred in the areas of the Middle and Lower Paraíba River, where few stretches showed downward trends. This recovery of degraded areas demonstrates the effectiveness of the actions provided for in the EIA/RIMA (2004), such as covering the sides of excavations with native species of the region in order to retain the land and revitalize riparian forests. Data from the Transparency Portal indicated the expenditure of more than 3.3 million Brazilian Reais in the revitalization, recovery and preservation of the São Francisco River and integrated basins of Northeast Brazil from 2005 to 2009 (CASTRO, 2011).

However, Resende and Santos (2019) state that the EIA/RIMA did not fully address the problems that were generated by the transposition of the São Francisco River. They lacked measures or presented ineffective measures in several preservation areas, in addition to lessening the impacts of the project. Thus, the upward trends in areas covered by natural formations in PPAs cannot be fully attributed to the actions associated with the transposition of the São Francisco River.

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The revitalization of riparian forests is one of the goals of the CBH-PB and counts on joint actions of the government and society. It should be noted that for the good collective management of water resources and PPAs of river basins, the population needs to participate along with correlated public entities, so as to directly and indirectly enhance the effectiveness of the actions (CARMO JÚNIOR, 2021).

After the statistical analysis, the Sankey diagrams of land use and land cover in the PPAs of the Paraíba River Basin were prepared for the periods established through the Pettitt test, presented in Figure 9 and Figure 10.

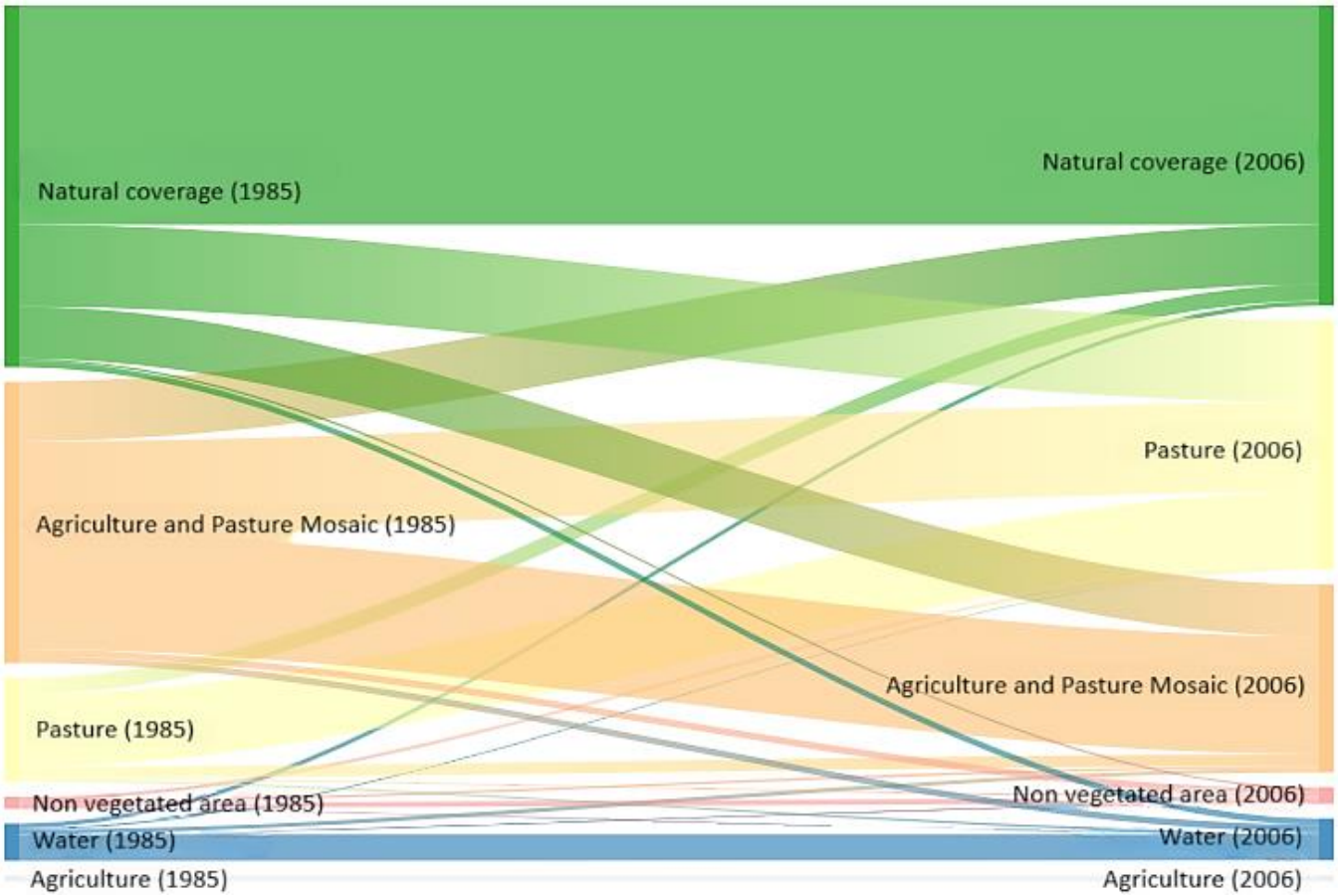

Figure 9 – Sankey diagram of land use and occupation in Permanent Preservation Areas (PPAs) of the Paraíba River Basin – 1985 to 2006. Source: The author (2022).

For the period from 1985 to 2006, there was a decrease of 17.0% in areas covered by natural formations, from 45.1% to 37.4%. The largest alterations in land use and occupation in the Paraíba River Basin consisted of the transformation of areas with natural cover into pasture and agricultural mosaics. Santos *et al*. (2019) found that the pasture class was responsible for the largest areas in conflict with land use in the Caldas

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River Basin – GO between 1985 and 2008, similarly to the Paraíba River Basin. As for non-vegetated areas and areas covered by water bodies, minimal changes were observed in these categories.

Figure 10 presents the Sankey diagram for the period from 2007 to 2020 and, although degradation of areas with natural cover still occurred, there was a recovery of 27.6% when the first and last years analyzed are compared, mainly from pasture and agricultural lands.

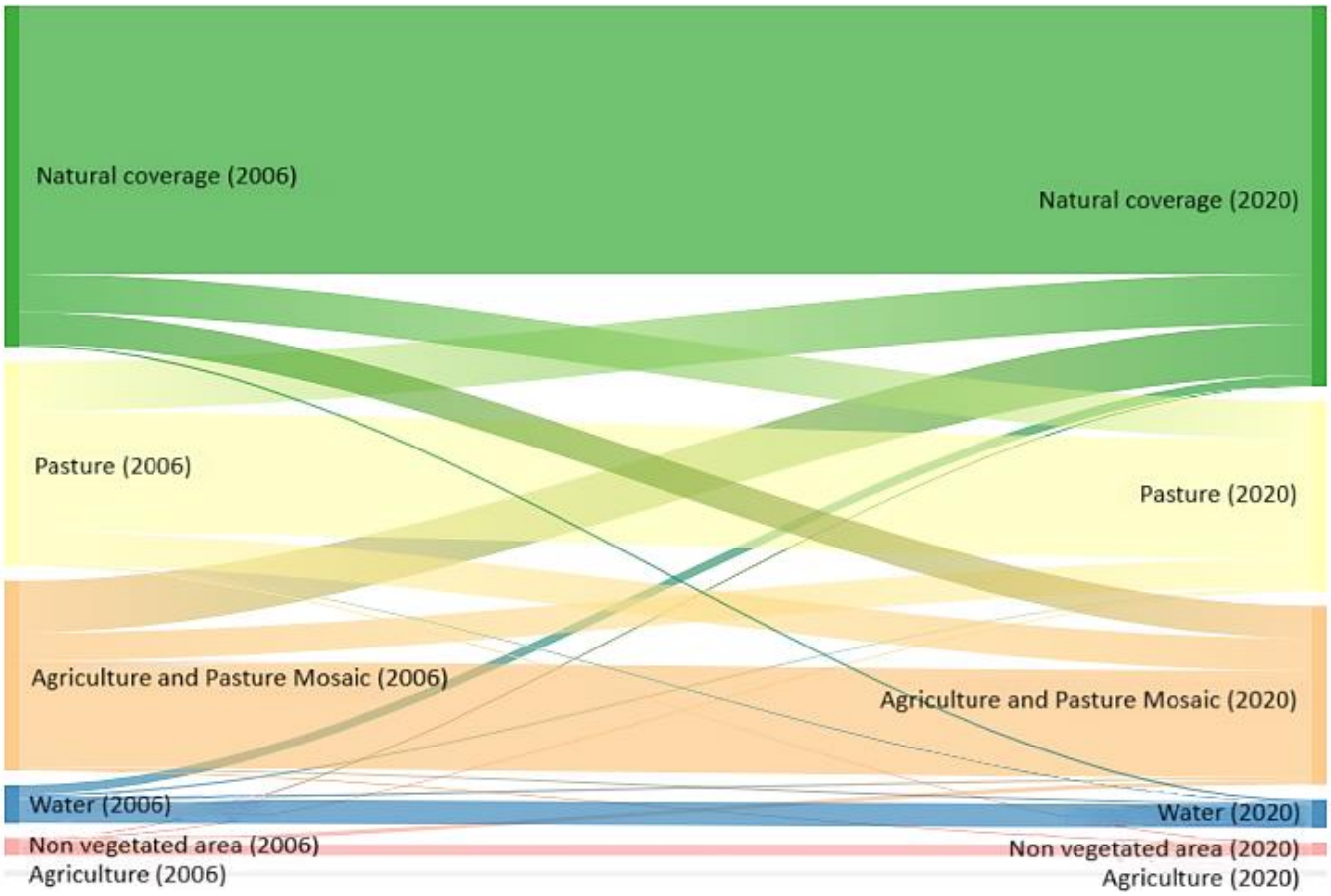

Figure 10 – Sankey diagram of land use and occupation in Permanent Preservation Areas (PPAs) of the Paraíba River Basin – 2007 to 2020.
Source: The author (2022).

IV. CONCLUSIONS

The time series analysis of land use and occupation showed significant changes in the riparian forests of the Paraíba River Basin caused by anthropogenic activities and actions implemented for the management and protection of natural resources in the studied area.

The Pettitt test showed a break point in the time trend of the series in 2006, which may be related to the creation of the CBH-PB and the beginning of the transposition of the São Francisco River, a work that proposed conservation measures aimed at riparian forests in the Environmental Impact Report (RIMA).

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Through the Mann-Kendall tests, it was found that there was a significant change in the trends of the time series when the periods from 1985 to 2006 and from 2007 to 2020 were compared, mainly in the Middle and Lower Paraíba River Regions. These areas showed upward trends in natural formations from 2007 to 2020.

The Sankey diagram provided a better visualization of the decrease of 17.0% in areas covered with natural formations in the period from 1985 to 2006, with a significant concomitant increase in areas covered by pasture and agriculture. For the period from 2007 to 2020, there was a recovery of 27.6% of areas with natural cover and within the limits of PPAs established by the current Forest Code.

The geoprocessing tools and statistical methodologies used in this study proved to be efficient for the time series analysis of vegetation and land use and occupation data. The application of such tools in the management and protection of natural resources in hydrographic basins is fundamental. It is recommended that the correlation of temporal data with information on water use grants for agricultural activities in the Paraíba River basin be investigated in further studies.

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