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ANALYSIS OF LAND USE AND OCCUPATION IN PERMANENT PRESERVATION AREAS IN THE MUNICIPALITY OF PATOS IN PARAÍBA

Análise do uso e ocupação do solo em áreas de preservação permanente do município de Patos-PB

Análisis del uso y la ocupación del suelo en las áreas de preservación permanente del municipio de Patos, en el estado de Paraíba

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ABSTRACT

The aim of this study was to identify the possible environmental impacts of the disorderly use and occupation of Permanent Preservation Areas (PPAs) in the municipality of Patos/PB. More specifically, the APPs of three watercourses were analyzed: the Riacho da Cruz, the Rio Espinharas and a derivative of the Rio Espinharas in the Belo Horizonte district. The APPs were delimited using QGIS software and the Google Hybrid add-on, generating buffers according to the limits established in Municipal Law No. 3,486/2006. The temporal analysis revealed a significant decrease in green areas (from 37.22% to 8.70%) and an increase in built-up areas (from 6.46% to 33.06%). On-site analysis revealed the presence of built-up areas within the APPs, in disagreement with current legislation. The main environmental impacts identified include the suppression of vegetation, soil sealing and the improper disposal of solid waste and effluents, negatively affecting biodiversity and local quality of life. It is recommended that the recovery of degraded areas be monitored and implemented, together with appropriate sewage and drainage projects to mitigate the impacts of the lack of occupational control in the areas.

Keywords: Water resources; Environmental conflicts; Remote sensing.

RESUMO

Este estudo visou identificar os possíveis impactos ambientais decorrentes do uso e ocupação desordenada em Áreas de Preservação Permanente (APPs) do município de Patos/PB. Mais especificamente, foram analisadas as APPs de três cursos d'água, o Riacho da Cruz, o Rio Espinharas e um derivado do Rio Espinharas no bairro Belo Horizonte. A delimitação das APPs foi realizada com o software QGIS e o complemento Google Hybrid, gerando buffers conforme os limites estabelecidos na Lei Municipal nº 3.486/2006. A análise temporal revelou uma significativa diminuição das áreas verdes (de 37,22% para 8,70%) e um aumento nas edificadas (de 6,46% para 33,06%). As análises *in loco* revelaram a presença de áreas edificadas dentro das APPs, em desacordo com as legislações vigentes. Os principais impactos ambientais identificados incluem a supressão da vegetação, impermeabilização do solo e o descarte de resíduos sólidos e efluentes inadequados, afetando negativamente a biodiversidade e a qualidade de vida local. Recomenda-se o monitoramento e aplicação de recuperação de áreas degradadas, aliada a projetos adequados de esgoto e drenagem para mitigar os impactos do descontrole ocupacional das áreas.

Palavras-chave: Recursos hídricos; Conflitos Ambientais; Sensoriamento remoto.

RESUMEN

El objetivo de este estudio fue identificar los posibles impactos ambientales del uso y ocupación desordenada de las Áreas de Preservación Permanente (APPs) en el municipio de Patos/PB. En concreto, se analizaron las APPs de tres cursos de agua: el Riacho da Cruz, el Río Espinharas y un derivado del Río Espinharas en el barrio de Belo Horizonte. Las APPs fueron delimitadas utilizando el software QGIS y el complemento Google Hybrid, generando buffers de acuerdo con los límites establecidos en la Ley Municipal nº 3.486/2006. El análisis temporal reveló una disminución significativa de las zonas verdes (del 37,22% al 8,70%) y un aumento de las zonas edificadas (del 6,46% al 33,06%). Los análisis in situ revelaron la presencia de zonas edificadas dentro de los APP, en desacuerdo con la legislación vigente. Los principales impactos ambientales identificados incluyen la supresión de la vegetación, el sellado del suelo y el vertido inadecuado de residuos sólidos y efluentes, afectando negativamente a la biodiversidad y a la calidad de vida local. Se recomienda el seguimiento y la implementación de la recuperación de las áreas degradadas, junto con proyectos adecuados de alcantarillado y drenaje para mitigar los impactos de la falta de control ocupacional en las áreas.

Palabras clave: Recursos hídricos; Conflictos medioambientales; Teledetección.

The formation and evolution of urban areas are direct reflections of the intrinsic need for human beings to connect, interact and organize themselves for the sake of collective well-being (Bispo; Levino, 2011). However, the accelerated growth of Brazilian cities has resulted in a series of structural problems, such as inadequate transportation systems, lack of basic sanitation, deficient water and electricity supply, as well as the lack of infrastructure to deal with extreme weather events (Honda et al., 2015). These problems were driven by the process of rural exodus and consequently by the industrialization of cities, leading to a disorderly process of spatial organization (Santos, 2021).

The lack of preparation of cities for this sudden population growth contributed to an unequal distribution of resources. Even today, unresolved infrastructure problems persist as the demand for housing, employment and public services, exacerbating inequality in living conditions (Sousa, 2018). This disparity is also reflected in the environmental sphere, where populations in situations of socioeconomic vulnerability often settle in areas more exposed to environmental risks, such as soil, air and water contamination, as well as in Permanent Preservation Areas (PPAs) and risk areas (Monteiro; Veras, 2017).

Land exploitation for urban purposes involves activities such as the removal of natural vegetation, soil compaction, deforestation, and the construction of infrastructure (Fernandes, 2019). From this perspective, Castro (2017) explains that excessive land exploitation, a significant consequence of urbanization, is a process that generates negative environmental impacts, resulting in changes to the landscape and relief. Furthermore, land exploitation also contributes to increased temperatures in urban areas, due to reduced evapotranspiration and the accumulation of heat on paved surfaces. This results in a phenomenon known as a heat island, where urban areas have higher temperatures than surrounding rural areas (Furtado et al., 2020).

In addition to the impacts of land use, urbanization is also closely linked to water pollution. Improper disposal of urban solid waste (MSW) and effluents also contributes to water pollution. The lack of adequate treatment systems and poor waste management result in the contamination of water resources, negatively affecting aquatic life and human health (Brito, 2020).

In addition to the impacts of urban development, it is essential to address the occupation of PPAs and risk regions, considering their interaction with socioeconomic vulnerability. The Brazilian Forest Code (Brazil, 2012) considers PPAs as ecological reserves with the fundamental purpose of mitigating the environmental impacts generated by human activities and natural events. This designation highlights the importance of preserving riverbanks and springs, helping to contain sedimentation in water bodies, reduce surface runoff and preserve biodiversity.

Furthermore, the importance of preserving PPAs is due to the fact that the environmental services provided to society by natural ecosystems are minimally maintained, even in the face of changes promoted by human action on the environment, such as water supply, combating climate change at different scales of scope, preservation of genetic heritage, not only by ensuring the survival of countless species of fauna and flora, but also

functioning as an ecological corridor for gene flow, and also maintaining the fertility and stability of soils and slopes (Alves; Medeiros, 2016; Fernandes, 2019; Medeiros et al., 2021).

Resolution No. 303 of the National Environmental Council (CONAMA) highlights the importance of fencing springs or water sources, even if intermittent, with a minimum radius of fifty meters, aiming at the adequate protection of the respective contributing river basin. This measure aims to preserve sensitive ecosystems and ensure the integrity of water resources, promoting sustainable practices in the urban context and contributing to environmental conservation.

Although the PPA is legally protected, many of the regions where it needs to be preserved have suffered human interference over time. The irregular occupation of these areas, whether for housing, agriculture or livestock purposes, intensifies environmental impacts along watercourses, increasing the risk of pollution of water resources and the degradation of riparian forests (Brito, 2020). This dynamic not only compromises water quality, but also increases the challenges faced by vulnerable communities, highlighting the importance of planning and management strategies that take these complex interactions into account.

The objective of this study is to identify the possible environmental impacts resulting from the disorderly use and occupation of PPAs in the municipality of Patos/PB, by mapping land use and occupation in the years 1985 and 2022, analyzing existing negative environmental impacts, with data obtained on site, and verifying the compliance of these standards with the guidelines established in legal instruments of municipal and national scope.

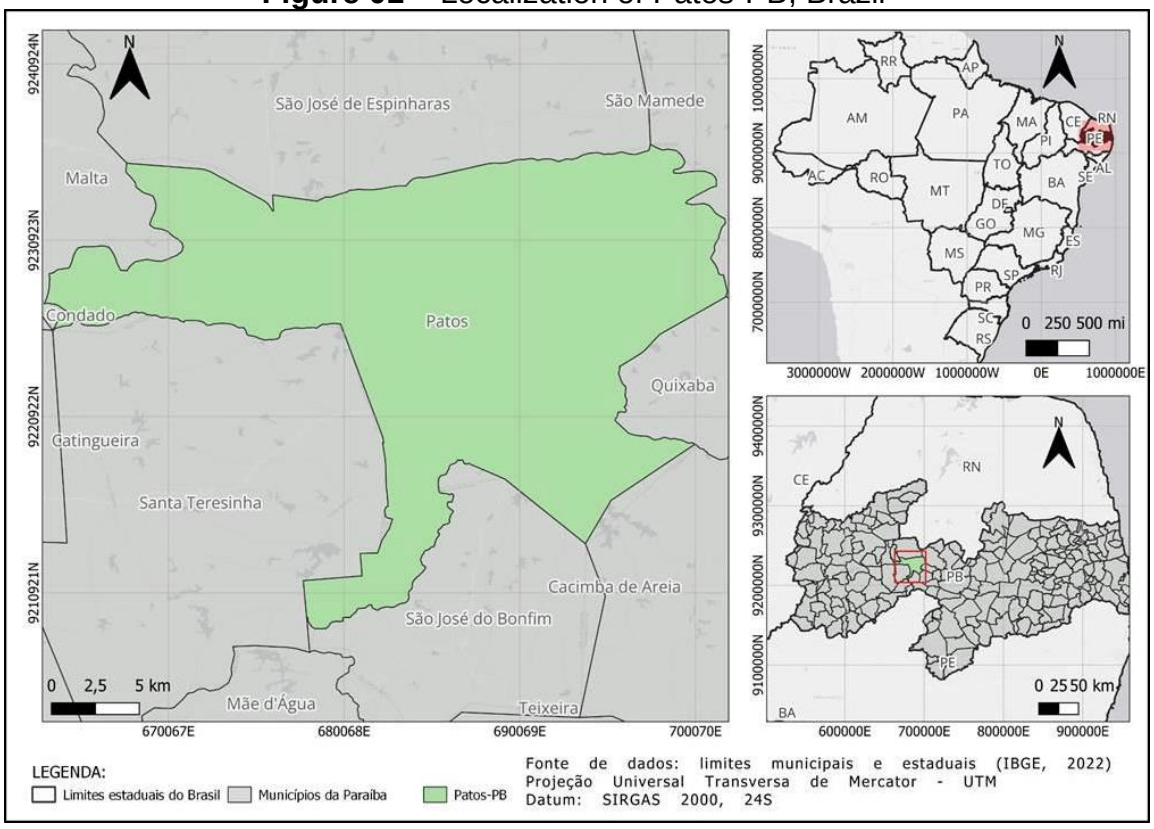
The results generated are expected to contribute to the generation of data applicable to the management of the area and provide important subsidies for decision-making, considering the urgent need to adopt measures that guarantee the preservation of natural resources in this current context.

2 CHARACTERIZATION OF THE STUDY AREA

The study in question was carried out in the municipality of Patos, in the intermediate region of Paraíba, located in the west of the state of Paraíba, as observed in Figure 01. The climate in Patos is predominantly semi-arid, with predominant vegetation of the Caatinga

type, with temperature variations of 28ºC to 35ºC per year, according to the Brazilian Institute of Geography and Statistics (IBGE, 2022) (Koeppen, 1996).

Figure 01 – Localization of Patos-PB, Brazil



Source: authors (2024).

The urban development of Patos has caused environmental impacts due to the increase in impermeability caused by paving or construction of buildings in areas that were previously permeable. In addition, the municipality is intersected transversally by the Espinharas River, formed by the Cruz and Farinha Rivers. These rivers originate on the slopes of the Serra do Teixeira-PB and join in the urban perimeter of the city of Patos-PB. With the imminent local urban growth, the populations began to increasingly deforest the riparian forest and degrade the springs that make up the PPAs of the watercourses that emerge in the municipality, causing serious environmental problems.

Regarding land use planning instruments, in the city of Patos, Law No. 3,503 of October 6, 2006, which establishes the Municipality's Integrated Development Master Plan, is in force. According to Article 17 of the aforementioned law, the Master Plan's main objective is to restrict population clusters from settling in unhealthy and dangerous

Permanent Preservation Areas or areas intended for economic, industrial, touristic expansion, and the like. This measure aims to ensure the preservation of these areas through monitoring, surveillance, and communication with residents' associations in neighborhoods and riverside regions.

Still on the subject of municipal land use planning instruments, in the city of Patos, there is the Municipal Council for the Defense of the Environment which defines PPAs as portions of the municipal territory, public or private, intended for the preservation of their relevant environmental and ecosystem characteristics, as established in Municipal Law No. 3,486, of May 9, 2006. Among the attributions of the Municipal Council, outlined in Art. 18, paragraph I, indicate the delimitation of legally protected environmental zones in the municipality, covering the Caatinga, riparian forests, hills, mountains, rocky elevations (Inselbergs) and rocky vegetation, considering the susceptibility of the environment to high risks. Additionally, according to Art. 21, permanent preservation zones are defined, specifying in their paragraphs I and II the areas of forest, riparian forests and protection strips of surface waters, springs and sources.

These measures aim to ensure the conservation and sustainable use of these areas, avoiding occupations that could compromise the integrity of ecosystems and cause negative impacts on the environment. In this way, the aim is to reconcile urban development with the protection of natural resources, promoting the preservation of ecosystems and the quality of life of the communities involved.

3 METHODOLOGICAL PROCEDURES

This study carried out a comprehensive analysis of land use and occupation in PPAs of watercourses within the urban perimeter of the municipality of Patos, using methodological procedures including cartographic survey, acquisition of satellite images and field visits. Initially, a cartographic survey was carried out to delimit the urban perimeter, in order to facilitate sampling of the study area. For this, the QGIS 3.28.9 software and the IBGE database (2022) were used. To delimit the municipal urban space, the data were manipulated and projected to the UTM coordinate system and Datum Sirgas 2000.

The study sample was then delimited. The methodology used initially involved the survey and mapping of watercourses that intersect the urban area of Patos. Subsequently, the watercourses that best represent the urban hydrographic network were identified,

considering criteria such as extension, relevance to the local community and potential environmental impact. Thus, the study sample was delimited using the intentional non-probabilistic sampling method, where the watercourses were deliberately chosen to be part of the sample, since only those that intersect the urban perimeter of the city of Patos were considered. The identification of the chosen collection points is presented in Chart 01.

Chart 01 – Selected collection points

Watercourse	Location of collection points	Identification of collection points
Derived from the Espinharas River	Belo Horizonte Neighborhood	01
	Belo Horizonte Neighborhood	02
Cruz Water Body	Monte Castelo Neighborhood	03
Espinharas River	Lagoa dos Patos Avenue	04
	Jardim Santa Tereza Neighborhood	05
	São Sebastião Neighborhood	06

Source: authors (2024).

The selection of collection points was based on the relevance of these watercourses to the urban context of the city, taking into account their proximity to inhabited areas and their importance for urban drainage. Field visits were carried out at the collection points to validate the information obtained from the satellite images, allowing a deeper understanding of the characteristics of the PPAs, documented with photographic records and notes. The selection of watercourses to be analyzed considered criteria such as representativeness, accessibility and relevance for the research, favoring those located in areas with high building density.

The delimitation of the PPAs was carried out using the Google Hybrid add-on of the QGIS software. It was possible to spatially represent the location of the watercourses through the manual generation of shapefiles. Finally, buffers were created based on the values described in Art. 21, paragraph I of the Municipal Council, where the permanent preservation zones are defined, as shown in Table 01.

Table 01 – Classes and dimensions of PPAs according to Municipal Law No. 3,486

Largura da margem	Área de preservação
≤ 10m	30m
between 10m to 50m	50m
between 50 to 200m	100m
between 200m to 600m	200m
≥ 600m	500m

Source: Municipal Law No. 3,486 (2006).

In a second step, a land use and land cover map was produced. For its preparation, images from the Landsat-5/TM satellite for the year 1985 and images from the Landsat-8/OLI-TIRS satellite for the year 2022 were used. Both images are available on the Google Earth Engine platform, which performs spatial processing and enables mapping of transformations in phenomena occurring on the Earth's surface. The classification was performed using the Random Forest classifier algorithm, which enables statistical classification using a decision tree and mapping of the area's characteristics based on a qualitative and quantitative analysis of the dynamics of land use and land cover (Gorelick et al., 2017).

The results were compared to the master plan to assess the effectiveness of the policies in reducing the detected environmental impacts, leading to an analysis of the adequacy and application of the legal instruments in Patos. This procedure also highlighted possible gaps, and adjustments were suggested for more sustainable land use management in the municipality.

4 RESULTS

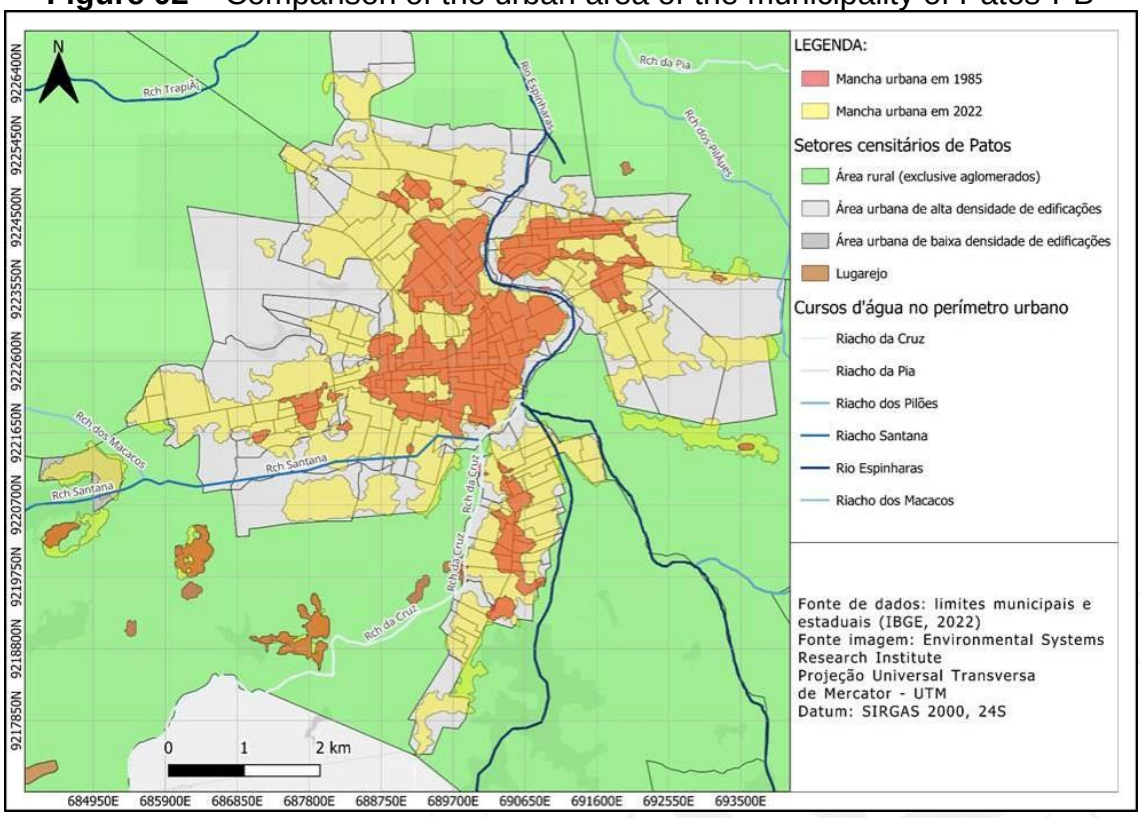
The following will present the results and discussions arising from the analyses carried out on the environmental impacts resulting from urban expansion in the PPAs in Patos-PB. These results were obtained through the evaluation of changes in land use patterns and environmental impacts in the PPAs of the selected watercourses, as described in the previous topic (Methodological procedures). The analysis includes the interpretation of data related to land occupation near the watercourses, in addition to discussing the

implications of these results, offering a comprehensive understanding of the challenges faced due to the irregular occupation of PPAs and the consequences for the environmental sustainability of the municipality.

4.1 Expansion of the urban fabric

The urban structure influenced by Iberian colonization is evident in the configuration of the city of Patos-PB, especially in the occupation of areas adjacent to water resources, as highlighted by Alves and Medeiros (2016). Figure 02 presents a visual comparison of the expansion of the urban area close to watercourses over a significant period of time, covering from 1985 to 2022. This analysis reveals not only the magnitude, but also the direction of urban growth in relation to water bodies, indicating a trend of continuous and intensive occupation of these areas over the decades.

Figure 02 – Comparison of the urban area of the municipality of Patos-PB



Source: authors (2024).

The figure 02 shows the land use and occupation scenario of the municipality of Patos, for the years 1985 (in red) and 2022 (in yellow). It can be seen that as the city

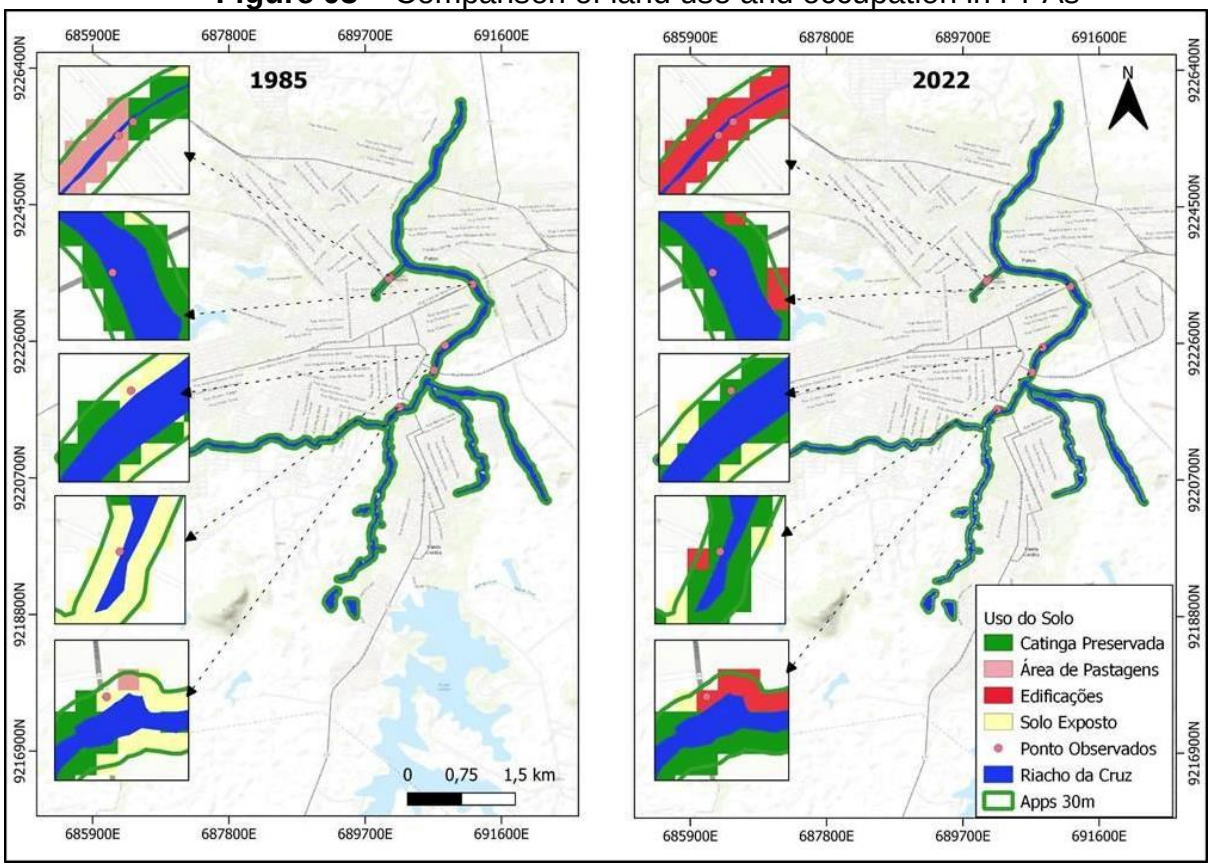
developed, the population settled increasingly close to the watercourses existing in the municipality, including building settlements and real estate developments in floodplain areas.

Despite the natural benefits provided by the proximity of watercourses, such as access to water and fertile soil, the disorderly occupation of these areas results in a series of environmental and social challenges, such as increased exposure to flood risks, contamination and degradation of watercourses, and loss of biodiversity. In the study by Alves and Medeiros (2016) on the environmental impacts and delimitation of the permanent preservation area of the Espinharas River in the urban stretch of Patos-PB, several environmental problems were identified in the Espinharas River, with the extinction of riparian forests standing out as one of the most critical problems in urban rivers. According to the authors, the removal of vegetation cover tends to make the river increasingly shallow, intensifying flooding in nearby areas and causing losses to the population of Patos.

Furthermore, Silva et al. (2023) also identified illegal activities in the Espinharas River PPA in their study on PPA recovery measures and their implementation in the urban area. According to the authors, there is a considerable number of buildings on the riverbanks, thus demonstrating a flexibilization in public administration, allowing constructions within PPAs, disregarding the requirements of the Forest Code and not adopting conservation strategies for the occupied areas, which directly affects the river ecosystem.

In this context, the delimitation of PPAs of the watercourses under study allows us to assess not only the extent of legally guaranteed environmental protection, but also allows for a more in-depth analysis of the interaction between urban growth and water resources. Under this context, a comparison of land use and occupation in PPAs of the municipality of Patos-PB was made between 1985 and 2022, offering a concrete visualization of changes over time, as shown in Figure 03.

Figure 03 – Comparison of land use and occupation in PPAs



Source: authors (2024).

Analyzing the maps presented in Figure 03, the evolution of the PPAs of the points selected in this study over the 37-year period is evident. The map on the left shows the land use patterns in the PPAs selected for the year 1985, while the map on the right represents the same for the year 2022. Land use was categorized into preserved vegetation, pasture areas, buildings, exposed soil and watercourses. From the visual analysis it is possible to identify changes in land use patterns, such as the transformation of areas of exposed soil and preserved caatinga into areas of buildings. These changes directly reflect the challenges mentioned above in relation to environmental impacts, such as flooding, associated with the irregular occupation of PPAs.

Thus, after obtaining and analyzing the data presented in Figure 03, the values of the Vegetation/Agriculture and Buildings areas were analyzed using the QGIS software, in order to understand the tendency of vegetation suppression and increased soil impermeability, as shown in Table 02.

Table 02 – Land use for the years 1985 and 2022

Land uses in PPAs	1985 (Area in %)	2022 (Area in %)
Vegetation/Agriculture	37,22	8,70
Buildings	6,46	33,06

Source: authors (2024).

From the analysis of the data presented in Table 02, the predominance of vegetation and agriculture can be observed in 1985, representing 37.22% of the PPAs, while buildings occupied only 6.46% of these areas. These numbers indicate an initially more balanced occupation, with a considerable portion of preserved vegetation and agricultural activities. However, the data for the year 2022 show a drastic transformation over the years. Vegetation and agriculture in the PPAs have reduced significantly, representing only 8.70% of the area, while buildings have increased to 33.06%.

Thus, it is possible to conclude that for the year 2022 the value obtained for the areas of impermeable soil was approximately 5 times greater than in 1985. The comparison of the areas of vegetation/agriculture for the same time interval followed a similar trend. Due to the increase in impermeable areas, the value obtained for the areas of exposed soil was approximately 5 times lower in 2022, when compared to the value obtained for the year 1985. These results are comparable to the analyses by Medeiros (2019), in his study on the diagnosis of environmental impacts in the PPA in the urban area of the Piancó River in Pombal - PB, a significant disparity was evidenced between the area of exposed soil and the fragments of riparian forest of the original coverage. The author states that, due to this change, the soil becomes vulnerable to the effects of natural agents (rain, sunlight, wind, among others) and to human actions, which are probably the main causes of the environmental degradation process of the PPA, making it more susceptible to erosion processes. In addition, the soil shows signs of disturbance and compaction.

From this perspective, the change found in the temporal analysis reflects an intensification of the urbanization and land occupation process, with a growing conversion of natural areas into urbanized spaces, which contributes to the reduction of biodiversity and increases vulnerability to events such as floods.

Therefore, the comparison between the uses in PPAs in the two periods clearly highlights the disorderly urban expansion and the pressure exerted on preservation areas, reinforcing the need for policies and actions that promote territorial planning and

environmental conservation to guarantee the sustainability of urban areas and the protection of water resources. Considering that the removal of vegetation in riparian forest areas is one of the main factors contributing to environmental degradation, representing a worrying stage for the stability of ecosystems, as highlighted by Speth et al. (2020).

4.2 Analysis of environmental impacts found in the PPAs under study

Over the last few decades, rapid changes in the landscape have triggered a series of alterations and destruction in natural environments. These unplanned changes have led to the fragmentation of natural spaces, causing isolation of habitats and damaging the biodiversity of fauna and flora (Maciel; Barbosa, 2015). In this context, the environmental transformations at the collection points presented in Table 01 of topic 3 (methodological procedures) were analyzed.

For the collection points designated as points 01 and 02 located in the Belo Horizonte neighborhood, on Antônio Firmino de Macedo and Horácio Nóbrega Streets, respectively, a derivation of the Espinharas River was noted, presenting a mixed configuration: a channeled part, as observed in Figure 04 (a), and another part preserved in its most natural state, as represented in Figure 04 (b).

Figure 04 – Collection points: a) R. Antônio F. de Macedo and b) R. Horácio Nóbrega

Source: authors (2024).

When analyzing Figure 04, the absence of preserved areas around the collection points is evident. In Figures 04 (a) and 04 (b), the presence of buildings within the PPAs and the inadequate disposal of effluents in the drainage channels can be observed. This situation results in the contamination of water resources, which negatively affects aquatic life and human health (Brito, 2020).

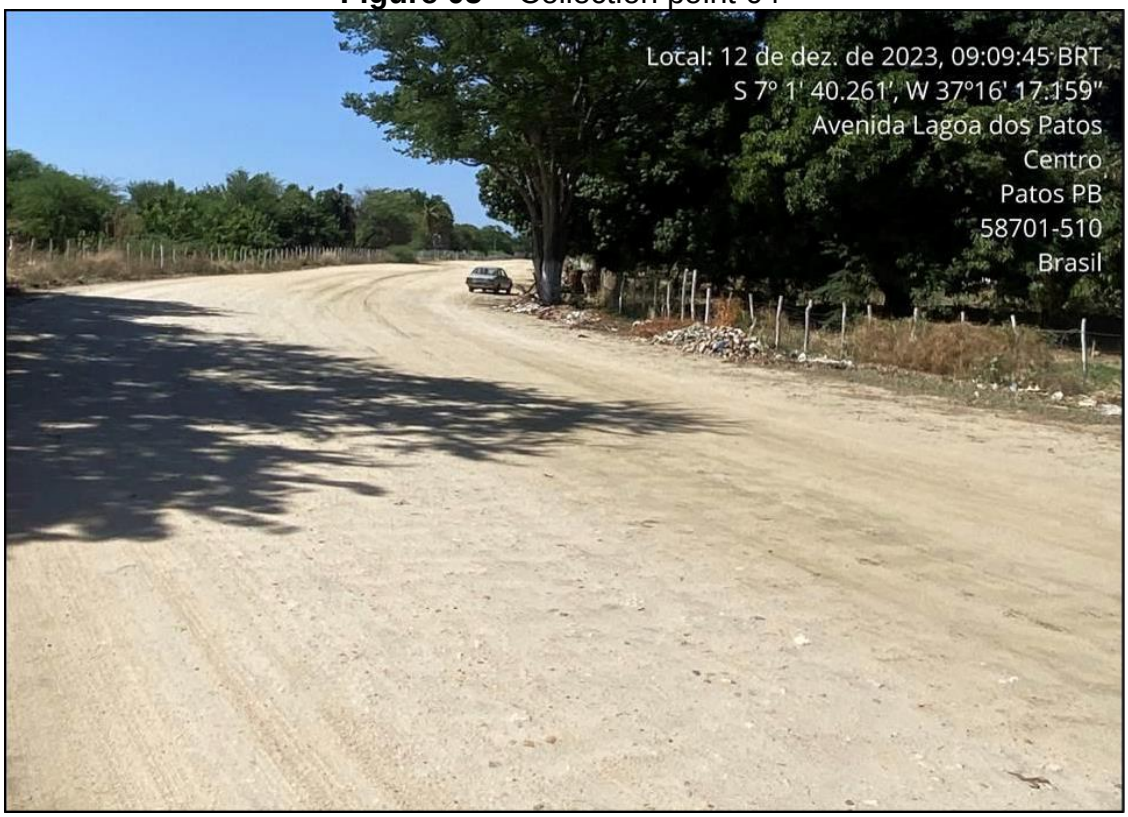
Furthermore, the presence of vegetation obstructing the edges of the channels and changes in soil characteristics were identified. The replacement of natural landscape characteristics by impermeable conditions reduces soil permeability, increasing surface runoff and the volume of water in the drainage system (Tucci, 1993). Thus, the configuration found at the collection points represents risks to both the health of the population and nearby infrastructure.

The impacts found corroborate recent analyses carried out in PPAs of urban watercourses (Alves; Medeiros, 2016; Medeiros, 2019; Silva, 2022). The presence of MSW, as well as the dumping of effluents into watercourses, are recurring problems that contribute significantly to the eutrophication process, due to the high load of organic matter and nutrients present in these effluents (Alves; Medeiros, 2016). These factors not only deteriorate water quality, but also alter potability standards, potentially making it unfit for human consumption and harming aquatic ecosystems.

At collection point 04, shown in Figure 05, excessive soil impermeability was identified due to the paving of Lagoa dos Patos Avenue. This work, intended to improve traffic flow from the south zone to the Brasília neighborhood, is underway along the banks of the Espinharas River. The avenue, approximately 600 meters long in both directions, includes cycle lanes, parking areas and sidewalks (Patos Online, 2023).

Despite the expected benefits in terms of urban mobility, it is important to highlight that the construction of paving works can lead to adverse environmental impacts, especially when carried out in a PPA. Excessive soil impermeability contributes to increased temperatures in urban areas, due to reduced evapotranspiration and heat accumulation on paved surfaces (Furtado et al., 2020). These environmental changes directly affect local biodiversity, aggravating the destruction and fragmentation of natural habitats, resulting in the loss of species and reduced quality of life for fauna and flora.

Figure 05 – Collection point 04



Source: authors (2024).

Furthermore, soil compaction and impermeability significantly increase surface runoff, reducing the soil's infiltration capacity and unbalancing the basin's water balance. This phenomenon, described by Tucci (2008), can cause environmental disasters such as floods and inundations. Another significant consequence of urbanization is the excessive exploitation of the soil, which, in addition to generating negative environmental impacts, as mentioned previously, is also linked to the modification of the landscape and relief (Castro, 2017). Figures 06 (a), 06 (b) and 06 (c), which correspond to Collection Points 03, 05 and 06, respectively, located in the Monte Castelo, Jardim Santa Tereza and São Sebastião neighborhoods, highlight the transformation of the landscapes due to the local population's living standards. This is reflected in a high rate of inadequate waste disposal.

Figure 06 – MSW disposal: a) Collection point 03; b) Collection point 05; c) Collection point 06

Source: authors (2024).

The indiscriminate practice of waste disposal, often linked to the absence of effective MSW management policies, has been shown to have significant impacts on the urban environment, as shown in Figures 06 (a), 06 (b) and 06 (c). Soil contamination by toxic substances present in waste can compromise its fertility and ability to support vegetation, directly affecting local biodiversity and reducing the quality of urban ecosystems.

These findings corroborate the study by Medeiros et al. (2021), which addresses the challenges faced in MSW management in the municipality of Patos-PB. According to the authors, although the entire urban population has access to the door-to-door urban waste collection service, the practice of disposing of waste on vacant lots, in the drainage channel and on the banks of the Espinharas River was observed, where the lack of environmental sensitivity on the part of the population was noticeable. Thus, there is a need for government intervention to implement corrective mitigating measures, in accordance with current legislation, aiming to ensure a satisfactory quality of life for the population and the preservation of the environment.

In this context, it can be stated that human interventions intensify the degradation

process of springs, especially due to the inadequate occupation of recharge areas. In this context, agricultural activities, improper land use, soil erosion, and the elimination of native vegetation in PPAs stand out. In addition, the construction of residences contributes to this scenario, with the untreated dumping of domestic effluents and the uncontrolled disposal of animal waste and, especially, solid waste (Copetti et al., 2022). Thus, still at collection point 06, located in the Monte Castelo neighborhood and represented in Figure 07 (a), the presence of livestock activities was observed within the preservation strip of Cruz Water Body. In addition, the invasion of this protected area is evident, as evidenced in Figure 07 (b).

Figure 07 – Invasions in Cruz Water Body PPAs: a) Building and b) Livestock

Source: authors (2024).

The degradation of these natural areas compromises soil stability, increasing the risk of erosion and silting of water bodies. This reduces the capacity of these areas to provide essential ecosystem services, such as regulating water flow and protecting biodiversity. In addition, the presence of livestock activities can lead to contamination of water resources with animal waste and chemicals used in agriculture.

Livestock farming is an activity known to cause negative impacts on the environment, with soil being the most directly affected resource. However, other resources, such as water and vegetation, are also impacted, some of which are unavoidable due to the nature of the activity carried out on site. However, others, such as the suppression of

vegetation, can be minimized by implementing methods to restore degraded areas (Resende et al., 2011). In addition, invasion by buildings results in the fragmentation and destruction of natural habitats, which leads to the loss of biodiversity and reduced connectivity between ecosystems.

Finally, to facilitate understanding of environmental impacts, Chart 02 was prepared, which consists of identifying environmental aspects and impacts in the study area. This analysis is associated with the activities surrounding the selected PPAs and was carried out based on data and information previously obtained through maps, field visits and photographs.

Chart 02 – Identification and analysis of environmental impacts found.

Activity	Neighborhood	Environmental aspect	Environmental impact
Livestock farming activities within the Cruz Water Body PPA area	Monte Castelo	Contamination of watercourses by organic waste (animal feces and urine); Soil erosion; Destruction of riparian vegetation; Eutrophication;	Deterioration of water quality; Risks to human health; Degradation of soil quality; Loss of habitat and biodiversity.
Occupation of PPAs	Belo Horizonte, Monte Castelo, Lagoa dos Patos Avenue, Jardim Santa Tereza and São Sebastião	Reduction in the natural filtration capacity of water; Reduction in flood protection; Alteration of natural landscapes and relief; Excessive soil waterproofing; Removal of vegetation/surface soil cover; Poor drainage; Deforestation.	Degradation of soil quality; Decrease in biodiversity, loss of habitat; Risks to human health; Death of aquatic organisms and impairment of aquatic ecosystems; Reduction in water infiltration and aquifer recharge; Increased risk of flooding and inundation; Contamination of watercourses.

Inadequate disposal of effluents within urban drainage channels	Belo Horizonte and Monte Castelo.	Water contamination; Decreased water quality; Infiltration of contaminants into soil and groundwater; Damage to biodiversity; Odor and visual impact; Infiltration of pollutants into the soil.	Risks to human health; Death of aquatic organisms and damage to aquatic ecosystems; Emission of unpleasant odors; Proliferation of vectors that transmit diseases; Eutrophication; Soil contamination.
Improper disposal of solid waste	Monte Castelo, Jardim Santa Tereza and São Sebastião.	Infiltration of contaminants into soil and groundwater; Visual pollution and bad smell; Proliferation of disease vectors; Implication for local fauna that may ingest or become entangled in the waste	Aesthetic impact and modification of natural landscapes; Emission of unpleasant odors; Risk of death of fauna and imbalance of local ecosystems; Risk of fires in areas with flammable waste; Proliferation of vectors that transmit diseases; Risks to human health.
Urban development in areas close to drainage channels	Belo Horizonte	Removal of vegetation/surface soil cover; Excessive soil sealing; Change in landscape and relief	Decreased biodiversity and habitat loss; Reduced water infiltration and aquifer recharge; Increased risk of flooding and inundation; Degradation of water quality and aquatic ecosystems; Aesthetic impact and modification of natural landscapes.

Paving of Lagoa dos Patos Avenue inserted within a PPA	Lagoa dos Patos Avenue	Deforestation; Removal of vegetation/surface soil cover; Excessive soil sealing; Change in landscape and relief	Degradation of soil quality; Decreased biodiversity and habitat loss; Reduced water infiltration and aquifer recharge; Increased risk of flooding and inundation; Aesthetic impact and modification of natural landscapes; Heat islands, discomfort and stress.

Source: authors (2024).

The activities presented in Chart 02 demonstrate the extent and severity of environmental impacts in the PPAs under study, highlighting the imprecision of environmental laws and the lack of effective inspections, contributing to the inadequate occupation of these areas. The practice of livestock activities, irregular occupations, inadequate disposal of effluents and solid waste disposal occur due to the lack of inspection and awareness, resulting in significant environmental degradation.

In this context, it is clear that the occupation of these areas is driven by the demand for space for agricultural and urban activities, exacerbated by the lack of viable alternatives and the lack of knowledge of the environmental consequences. The lack of continuous monitoring policies and strategies for the recovery of degraded areas aggravates the situation, highlighting the urgent need for the review and rigorous implementation of environmental legislation.

4.3 Compliance with environmental legislation

The temporal analysis reveals a significant transformation in PPAs over the years. Evidencing a worrying reduction in vegetation and agricultural areas, replaced by urban expansion, which reflects a failure to comply with environmental preservation measures and indirectly points to the intensification of conflicts and negative impacts in PPAs, such as silting, water contamination and soil erosion.

The on-site analysis found that there are areas with a high density of buildings within

the PPAs. This observation raises concerns regarding compliance with current environmental legislation. According to Municipal Law No. 3,486/2006, it appears that the minimum limits of the PPAs are not being adequately respected. Although the restriction of irregular occupation of the banks of rivers, dams and reservoirs is embodied in the objectives of the master plan in its Art. 30, item XVIII, this practice is recurrent in the municipality, given that the city had its territorial development around the watercourses that flow into the Espinharas River.

Furthermore, the notable suppression of vegetation in PPAs contravenes the provisions of art. 7 of Law 12.651/2012 of the Brazilian Forest Code, which establishes the obligation to maintain vegetation in permanent preservation areas by owners, possessors or occupants, whether they are individuals or legal entities, under public or private law.

Furthermore, the identification of inappropriate effluent discharge at collection points 01 and 02 contravenes the provisions established by CONAMA Resolution No. 357/2005. As described in Chapter IV of this resolution, conditions and standards are established for the discharge of effluents, which can only be discharged directly or indirectly into water bodies after undergoing due treatment. The discovery of these inappropriate practices highlights the urgency of corrective measures and the need for greater monitoring to ensure the environmental protection of PPAs and compliance with environmental legislation.

5 FINAL CONSIDERATIONS

The use of geotechnologies, combined with remote sensing data and GIS, facilitated the analysis of conflicts in PPAs in the selected locations. Through the maps generated, significant urban expansion was evidenced over the years, specifically near water bodies. In addition, a reduction in pasture areas was observed in several points, indicating a transition from rural to urban environments. These results suggest the existence of problems in PPAs and point to a possible lack of compliance with environmental preservation measures.

The transformation observed in land use patterns between 1985 and 2022 reflects a drastic reduction in vegetation and agricultural areas replaced by buildings, highlighting the urgent need for land use policies that prioritize environmental conservation and urban sustainability. The environmental impacts identified in the analyzed points reveal a series of significant effects on local biodiversity, including the suppression of vegetation in floodplain

areas, soil sealing and the inadequate disposal of solid waste and effluents, negatively affecting biodiversity and local quality of life.

Climate change, exacerbated by phenomena such as El Niño, has intensified extreme weather events such as floods and droughts, highlighting the importance of urban planning that respects environmental laws. Therefore, it is crucial that urban development considers environmental preservation measures, such as maintaining vegetation areas and protecting PPAs, to mitigate the impacts of these changes. Proper planning can significantly reduce the risks to the city and its population, ensuring resilience against the adverse effects of climate change and promoting a more harmonious coexistence with the environment.

Therefore, to mitigate these impacts, it is essential to reinforce the implementation and monitoring of environmental legislation and promote awareness and environmental education campaigns for the population, encouraging sustainable practices and the protection of PPAs. In addition, compensation and mitigation measures are essential, including compensation for damages, reforestation, sustainable management practices, zoning and land use restrictions, resettlement, as well as sewage and drainage projects suited to the needs of the municipality.

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