Changes in land use and land cover in Pinheiro, Maranhão (1985–2024): integration between remote sensing and citizen science

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Abstract:

This study analyzes spatio-temporal changes in land use and land cover in the municipality of Pinheiro, Maranhão, from 1985 to 2024, integrating remote sensing data, geoprocessing techniques, and citizen science observations. The dynamics of land use and land cover were assessed using MapBiomas data derived from Landsat images (spatial resolution of 30 m) for the entire time series and Sentinel-2 images (10 m) for the most recent years, enabling the identification of long-term trends and more detailed spatial patterns. The results indicate the predominance of forest formations throughout the period analyzed, accompanied by a progressive reduction in natural vegetation and floodplains, in contrast to the significant expansion of pasture areas and the gradual growth of urban areas, highlighting the increase in anthropogenic pressures on the municipal landscape. As a complementary approach, field activities were carried out with high school students from IFMA – Campus Pinheiro, using the GLOBE Observer application. In total, 363 georeferenced observations were recorded, which contributed to the visual validation of land use and land cover classes and to the interpretation of local dynamics. The integration of remote sensing and citizen science proved to be a robust approach for monitoring changes in land use and land cover at the local scale. In addition to generating environmental data, the study highlights the educational potential of citizen science in strengthening scientific literacy, environmental awareness, and student engagement, providing relevant inputs for territorial planning and sustainable environmental management in the Baixada Maranhense region.

1. **Research Question and Hypothesis:**

1.2 Research Problem

How does the integration of spatio-temporal analyses of land use and land cover (LULC), derived from remote sensing data, and field observations obtained through citizen science, through the GLOBE Program, contribute to understanding land use dynamics and supporting territorial planning in the municipality of Pinheiro, Maranhão?

1.3 Hypothesis

It is hypothesized that, in the municipality of Pinheiro, Maranhão, between 1985 and 2024, there was a significant expansion of pasture and urban areas, to the detriment of forest formations and wetlands, reflecting anthropogenic conversion processes associated with the intensification of agricultural activities and urban expansion.

2. **Introduction and Review of Literature:**

Soil is the physical and ecological foundation that sustains life on Earth, and is a critical component for global food security, the regulation of biogeochemical cycles, and the maintenance of the planet's biodiversity. Its multiple functions, now understood by science as ecosystem services, are fundamental to environmental balance and human well-being. In this sense, Vezzani (2015, p. 673) points out that “the biodiversity of an ecosystem happens from the soil,” highlighting its role not as a simple substrate, but as a living and dynamic system on which the entire web of terrestrial life depends. Therefore, understanding and preserving the health of this finite and non-renewable resource on a human scale becomes an essential premise for any discussion on sustainability.

In recent decades, anthropogenic actions related to land use and land cover, such as urban expansion, conversion of natural areas to agriculture, and deforestation, have been

widely recognized for profoundly altering environmental processes. Studies indicate that these transformations lead to reduced water infiltration into the soil and increased erosion, as the replacement of natural vegetation with impervious surfaces reduces water retention capacity and accelerates surface runoff, intensifying sediment transport and soil degradation (Akpoti et al., as cited in Horton et al., 2022; Viola et al., 2014).

Global research also shows that agricultural and urban expansion has contributed to the loss of organic carbon in the soil and increased greenhouse gas emissions, with deforestation resulting in high rates of carbon release into the atmosphere (Hansen et al., 2021). In addition, changes in land use and land cover are associated with a reduction in habitat and ecosystem services, affecting biodiversity and biogeochemical cycles, as well as altering hydrological regimes and water quality (Singh, 2024). These multifaceted impacts underscore the importance of monitoring and understanding LULC dynamics to support sustainable environmental policies and land use planning.

Land use and land cover (LULC) analyses are essential to support rational territorial planning and the management of anthropogenic activities associated with urban expansion and infrastructure development in the municipality of Pinheiro, since unplanned changes can intensify environmental impacts and compromise the effectiveness of sustainable public policies. Scientific studies indicate that changes in LULC contribute directly and indirectly to environmental degradation, affecting air and water quality, hydrological processes, the resilience of ecosystems to extreme events, and increased carbon emissions (Zhang et al., 2022; Seixas et al., 2025).

In the context of the state of Maranhão, changes in land use and land cover are associated with territorial occupation and anthropogenic pressures that transform the natural landscape, driven by the expansion of agricultural areas and urbanization. Studies on land use dynamics in the state of Maranhão show that changes in land cover patterns in regions such as Baixo Munim reflect an increase in anthropogenic surfaces replacing natural cover, which has direct implications for the regional environmental structure (Souza et al., 2023). Research in urban areas shows that the Uncontrolled urban growth increases soil sealing, reducing water infiltration and altering hydrological regimes, which can intensify water body

contamination processes and increase environmental vulnerability in areas prone to flooding and soil degradation (Seto, Guneralp; Hutyra, 2011). These findings reinforce the need for continuous and integrated monitoring of land use in the municipality of Pinheiro to support territorial planning and sustainable environmental management.

In this scenario, the GLOBE (Global Learning and Observations to Benefit the Environment) Program (https://www.globe.gov) is an international initiative that has been in place since 1995, aimed at integrating education, science, and environmental monitoring (GLOBE, 2024). Programs of this nature are strategic because they provide field data that assist in the calibration, validation, and interpretation of information derived from remote sensing, especially that used in the analysis of land use and land cover. In Maranhão, and particularly in the municipality of Pinheiro, located in the Baixada Maranhense, the landscape has undergone changes associated with the intensification of urban occupation, agricultural practices, and the use of aquatic environments, elements that directly influence local environmental dynamics. This is a region with high socio-environmental complexity, marked by river and lake systems and areas subject to periodic flooding, which highlights the importance of continuous monitoring strategies. The GLOBE Observer application, through the land cover protocol, promotes the training of participants and enables the recording of georeferenced observations, supported by photographic images and surface classification, making this information immediately available for environmental analysis on a local scale.

The relevance of this study lies in understanding the impacts of changes in land use and land cover on the environment and local populations. The analysis of LULC changes in the municipality of Pinheiro allows for the identification of land use patterns associated with both environmental degradation processes and natural resource conservation. In addition, the participation of local students through the GLOBE (Global Learning and Observations to Benefit the Environment) Program, integrated with the STEAM (Science, Technology, Engineering, Arts, and Mathematics) methodology, contributes to strengthening science education and community engagement in environmental monitoring and protection.

In this context, environmental education plays a strategic role in educating young people to understand and interpret the dynamics related to land use and land cover. The participation of high school students from the Federal Institute of Maranhão (IFMA) in scientific initiatives, such as the GLOBE Program (Global Learning and Observations to Benefit the Environment), enables the application of standardized protocols for environmental observation and monitoring, contributing to scientific literacy and the development of critical thinking. By involving students in the collection and analysis of data on land use, the GLOBE Program promotes the integration of science, education, and sustainability, strengthening youth engagement in environmental management and in building responses to contemporary socio-environmental challenges (The GLOBE Program, 2024; Brazil, 1999).

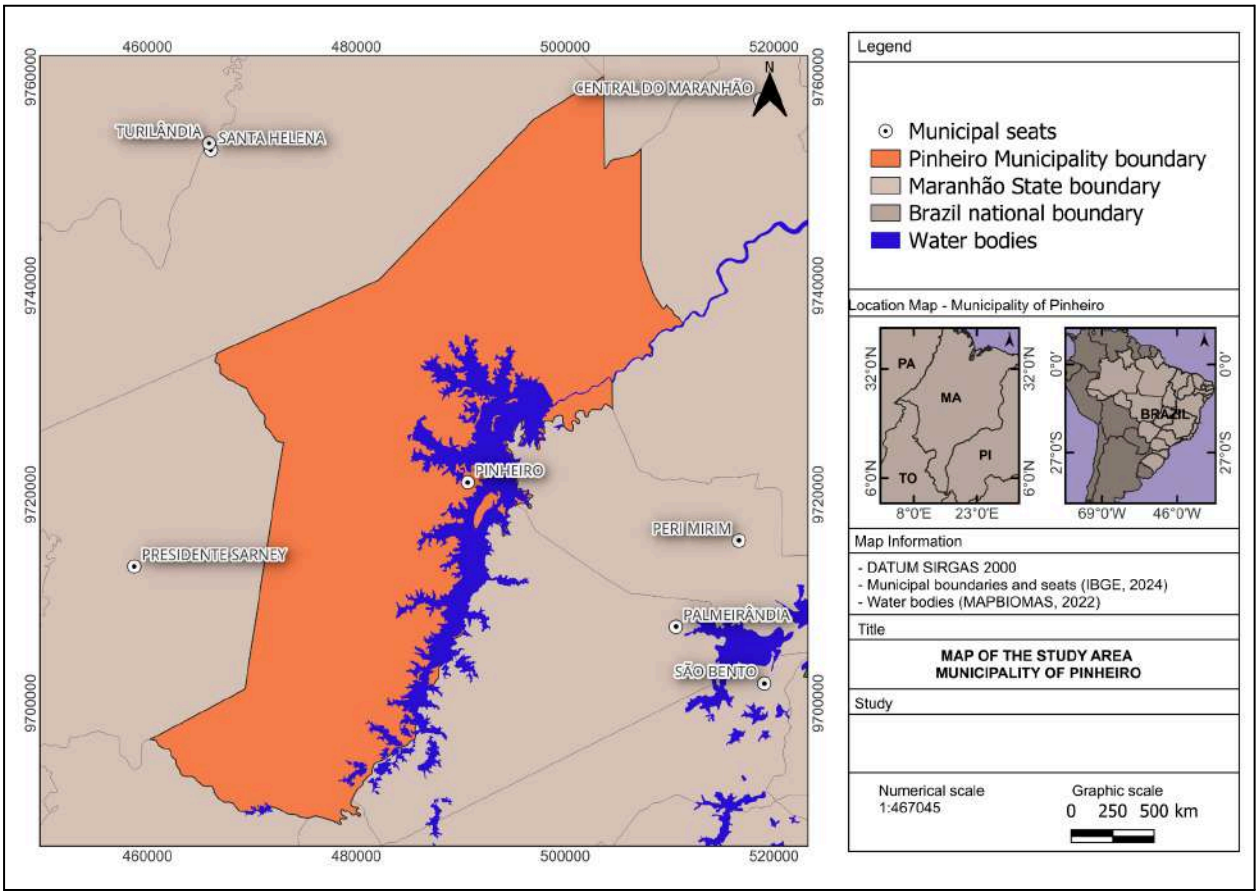
Despite advances in studies on land use and land cover change in Brazil, there are still few analyses that integrate long time series, local validation, and participatory strategies at the municipal level, especially in the Baixada Maranhense region.

3. Research Methods and Materials:

3.1 Study Area

The research was conducted in the municipality of Pinheiro, Maranhão, located in the Northern Mesoregion of Maranhão and Microregion of Baixada Maranhense, a region characterized by humid ecosystems, with floodplains and transition between the Amazonian and Cerrado biomes. The local climate, according to normal data from the National Institute of Meteorology (INMET), is classified as tropical (Aw), with a well-defined rainy season, usually concentrated in the first months of the year, and a dry season. The main economic activities in the region involve agriculture, fishing, livestock, and trade (Figure 1).

Figure 1 – Location of the study area in Pinheiro, Maranhão, Brazil.



Source: Author's own elaboration.

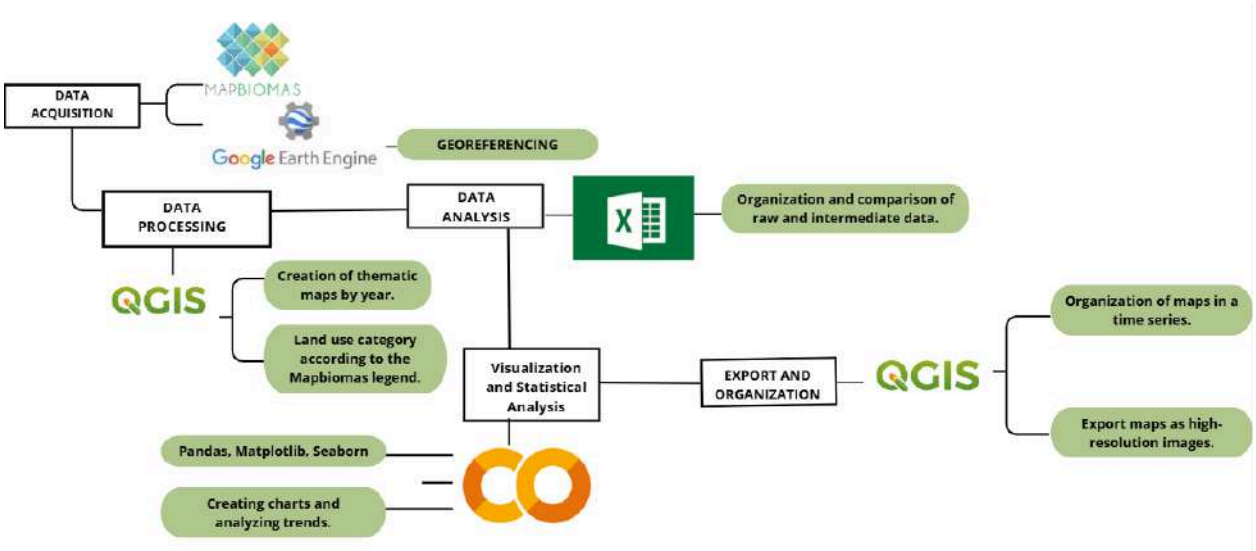
3.2. Data summary and analysis

The methodology employed in this research was structured in such a way as to directly relate the data analyzed to the objectives and questions of the study, combining quantitative and qualitative procedures to understand changes in land use and land cover in the municipality of Pinheiro. To this end, data obtained from the GLOBE Program protocols were used, with emphasis on the Land Cover protocol, which enables the characterization of the landscape through visual observations, georeferenced photographic records, and satellite images, which are later compared with remote sensing data.

The analysis of changes in land cover and land use in Pinheiro from 1985 to 2023 was based on data from MapBiomas Collection 10, compiled from Landsat satellite images with a spatial resolution of 30 meters. These data were obtained using the Google Earth Engine

platform and processed in QGIS 3.34 LTR software, enabling the creation of annual thematic maps. The systematization of area information, expressed in km², was performed in Excel Online, while statistical analyses and graph construction took place in a Python environment in Google Colab. The integrated use of these tools facilitated the efficient processing of geospatial data and the identification of patterns and trends over time. In order to compare the results obtained with data of higher spatial resolution, the MapBiomas BETA Collection was also used, covering the period from 2016 to 2023. This collection, still in the validation phase, represents an advance in the annual mapping of land use and land cover in Brazil, using Sentinel-2 satellite images with a resolution of 10 meters, following a methodology and legend similar to those of MapBiomas Collection 7.1 (Figure 2).

Figure. 2 Methodological flowchart.



In addition, field activities were developed with first-year high school students from IFMA, members of the technical course in Environment, in the municipality of Pinheiro, with the purpose of promoting the integration between theory and practice on the concepts of land cover. The activity involved the participation of 30 students, previously trained through the GLOBE Program and the STEAM approach. During the field activities, students used the GLOBE Observer app to record environmental observations, including information on land cover. The data collected contributed to the GLOBE database and was later integrated with information from MapBiomas, enabling a more comprehensive analysis (Figure 3).

Figure 3. Training stages and collection activities carried out by IFMA students – Pinheiro Campus: **(a), (b), (c)** e **(d).**

(a)

(b)

(c)

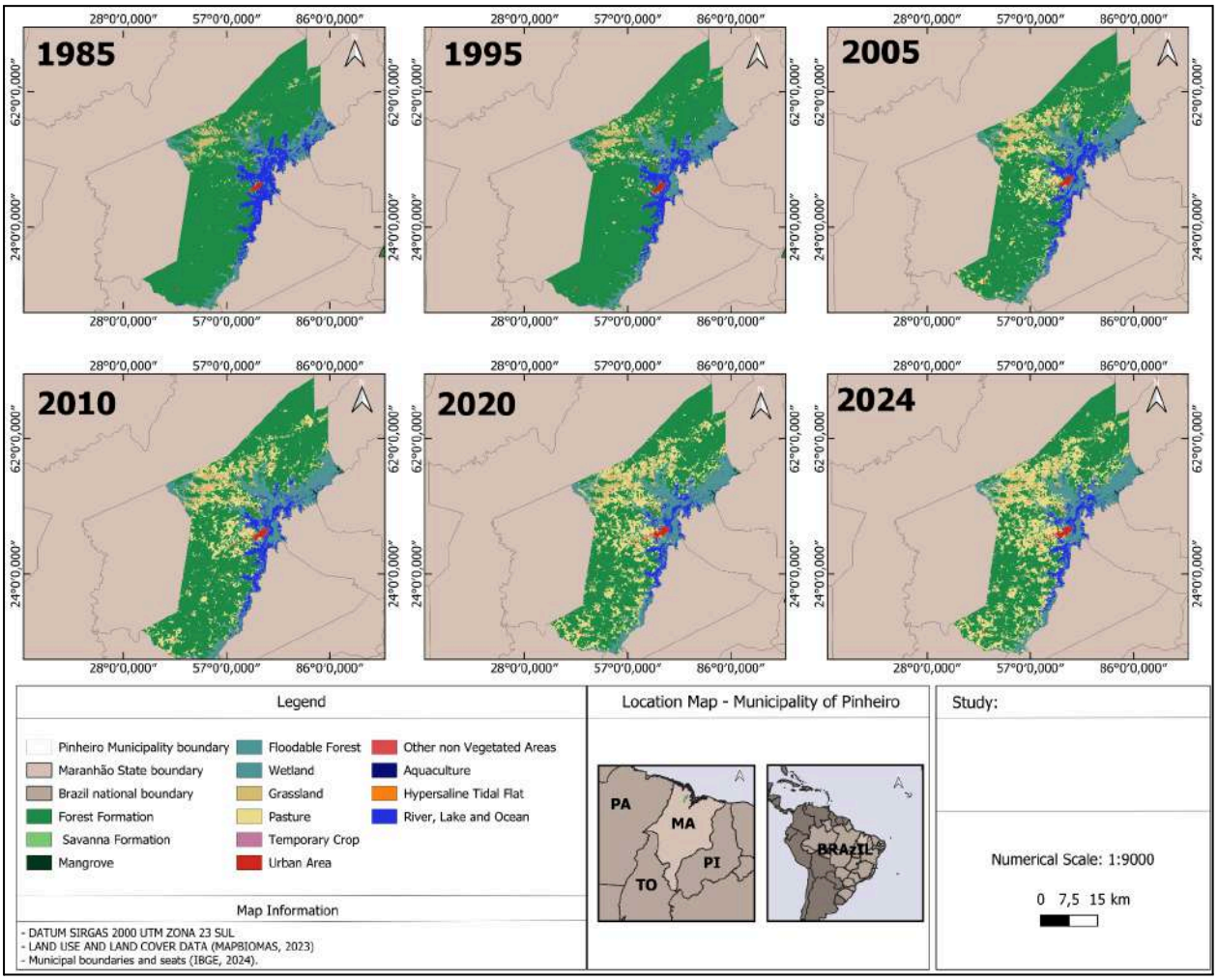
(d)

4. Results

Figure 4 shows the distribution maps and the evolution of land use and coverage in the municipality of Pinheiro, Maranhão, from 1985 to 2024, based on Landsat satellite images with a spatial resolution of 30 meters. Throughout the period analyzed, we observed the predominance of forest formations and rivers, lakes, and oceans, in addition to mangroves, flooded fields, swampy areas, and pastures. Urban areas appear sporadically in

1985 and 1995 and become more evident in the more recent periods, 2020 and 2024, concentrated mainly near the municipal seat of Pinheiro.

Figure 4. Pinheiro land cover change analysis 30m - 1985 to 2024.

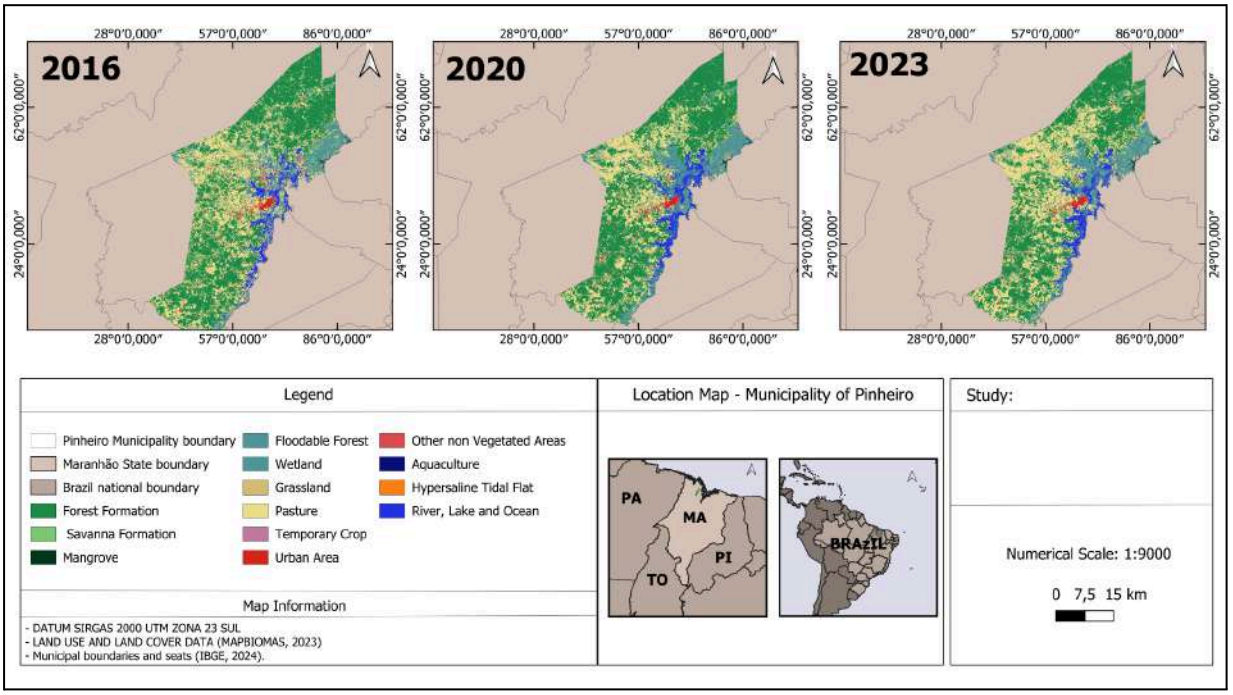


Source: Author's own elaboration.

Apicum, Floodplain Forest, and Campestre Formation make up the mosaic of land use and land cover throughout the period analyzed. These have a spatial distribution mainly associated with the coastal areas and hydrological influence of the municipality, with Apicum concentrated in estuarine zones, while Floodplain Forest occurs in areas subject to periodic flooding. It can be observed that the Campestre Formation appears in a more fragmented form and with less spatial expression, evidencing a dynamic of conversion to other uses, especially pasture, over the years.

Figure 5 shows the land use and land cover distribution maps for the municipality of Pinheiro, Maranhão, for the years 2016, 2020, and 2023, prepared from images with a spatial resolution of 10 meters, which provided a higher level of detail compared to maps derived from 30-meter images. This higher resolution enabled a more accurate representation of the maps, showing more clearly the spatial configuration of urban areas, water bodies, and coastal ecosystems, such as mangroves and apicum areas.

Figure 5. LAND COVER CHANGE ANALYSIS 10M - 2016 to 2023.



Source: Author's own elaboration.

Throughout the period analyzed, forest formations and rivers, lakes, and oceans remained predominant, accompanied by the significant presence of mangroves, flooded fields, swampy areas, and pastures. Urban areas became clearer and more clearly defined on the 2020 and 2023 maps, concentrating mainly around the municipal seat of Pinheiro and along urban expansion axes. The Floodplain Forest and Campestre Formation also composed the mosaic of land use and cover, presenting a spatial distribution associated mainly with estuarine and coastal zones and areas under the influence of the hydrological regime. It was noted that the higher spatial resolution allowed for a more detailed identification of the fragmentation of the Campestre Formation and its progressive conversion to pasture areas,

reinforcing the influence of anthropic activities on the dynamics of land use and occupation in the municipality.

According to the values presented in Table 1, the municipality of Pinheiro, Maranhão, showed changes in land use and land cover between 1985 and 2024. Noteworthy was the significant reduction in Forest Formation, which decreased by 345.19 km², from 1,116.32 km² to 771.13 km², as well as Savanna Formation, which decreased by 8.85 km², from 12.53 km² to 3.68 km². Areas associated with wetlands also underwent significant changes, notably the reduction in Floodplain Forest, which lost 39.91 km², falling from 69.71 km² to 29.80 km², while Wetlands showed the opposite behavior, increasing by 107.28 km², expanding from 92.93 km² to 200.21 km². The Campestre Formation shrank by 15.10 km², from 59.62 km² to 44.52 km², while Mangroves registered a slight increase in area, growing by 0.71 km², from 1.32 km² to 2.03 km².

Table 1. Land use transition table from 1985 to 2023 at a resolution of 30 meters.

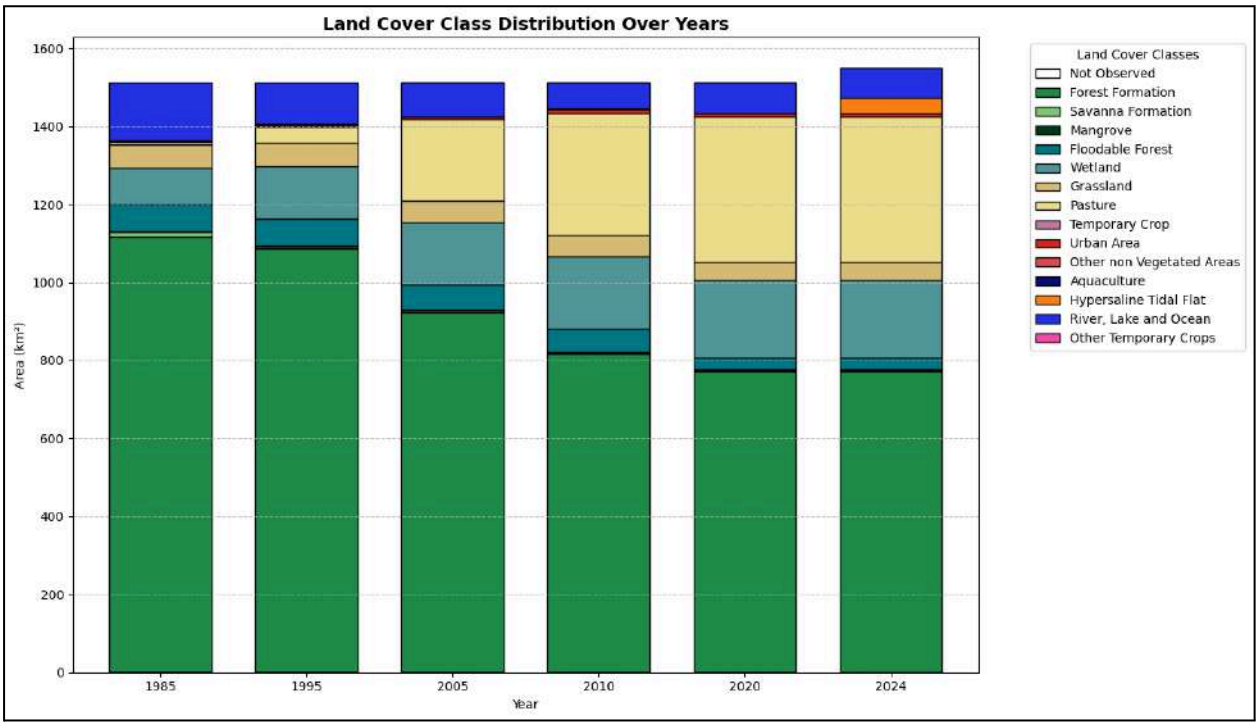
CLASS	1985	2024	Change (1985–2024)
Not observed	0.28	0.26	-0.02
Forest Formation	1116.32	771.13	-345.19
Savanna Formation	12.53	3.68	-8.85
Mangrove	1.32	2.03	+0.71
Floodable Forest	69.71	29.80	-39.91
Wetland	92.93	200.21	+107.28
Grassland	59.62	44.52	-15.10
Pasture	7.03	372.07	+365.05
Urban Area	4.21	10.16	+5.95
Other non Vegetated Areas	0.65	1.19	+0.54

Source: Author's own elaboration.

In contrast, pastureland showed the greatest expansion in the period analyzed, with an increase of 365.05 km², from 7.03 km² in 1985 to 372.07 km² in 2024, evidencing the intensification of agricultural activities in the municipality. Growth was also observed in urban areas, which increased by 5.95 km², from 4.21 km² to 10.16 km², indicating a continuous process of urban expansion. Other non-vegetated areas showed a slight increase of 0.54 km², ranging from 0.65 km² in 1985 to 1.19 km² in 2024. On the other hand, the Unobserved class showed a slight reduction of 0.02 km² over the period.

The graph shows the distribution of land use and land cover areas over the years 1985, 1995, 2005, 2010, 2020, and 2024 (Figure 6). Throughout the period analyzed, Forest Formation remained the dominant class, although it showed a progressive reduction in area over the decades, with this trend continuing until 2024.

Figure 6. LAND COVER CHANGE ANALYSIS 30M - 1995 to 2024.

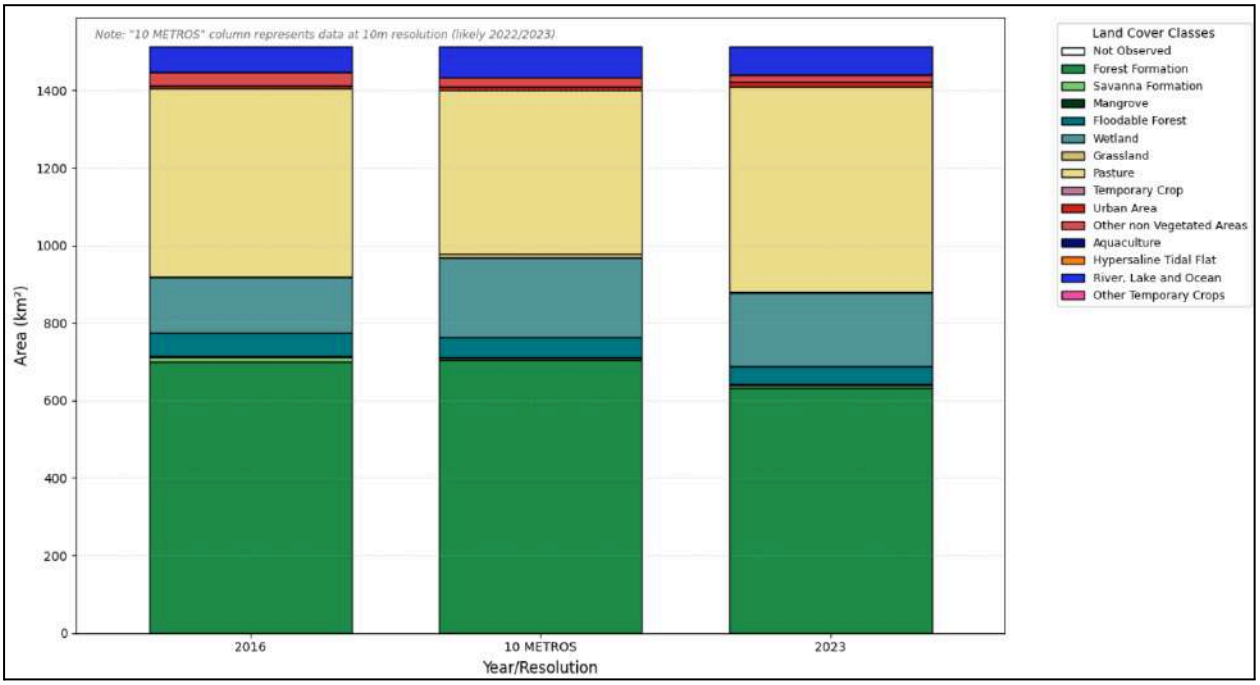


Source: Author's own elaboration.

Pastureland showed continuous growth throughout the time series, with more pronounced expansion from 2005 onwards, making it the class that increased the most during the period analyzed. Wetlands showed interannual variations, with a clear upward trend between 2005

and 2024, while Floodplain Forests exhibited the opposite behavior, with a progressive reduction in area over the period. Urban Areas and Other Non-Vegetated Areas remained small in spatial terms, but showed gradual growth, especially after 2010. Mangroves, savanna formations, and grassland formations showed less significant variations, maintaining relatively stable areas when compared to the more dynamic classes, a pattern similar to that observed in regional studies on land use and land cover dynamics in the Brazilian Amazon (MapBiomas; Imazon, 2024).

Figure 7. LAND COVER CHANGE ANALYSIS 10M - 2016 to 2023.



Source: Author's own elaboration.

Pasture areas showed a tendency to expand, especially in the 10-meter classification and in the year 2024, making it one of the classes that increased the most during the period. Savanna formation, on the other hand, showed a trend of reduction in area over the time series. The classes of grassland and wetlands showed moderate variations between years, reflecting both the natural dynamics of the environment and possible seasonal and hydrological influences, while floodplain forest showed a progressive reduction in area. Urbanized areas and other non-vegetated areas remained with a reduced share of the

landscape, although they showed slight increases, especially in the analysis at higher spatial resolution (Figure 7).

Table 2 shows the number of collections made by high school students using the GLOBE Observer app. It can be seen that the students managed to record 363 observations, demonstrating active participation and involvement throughout the proposed activity. The number of collections shows that the use of the app was understood and executed appropriately by the students, even though it was the first contact many of them had with citizen science tools.

In addition to numerical records, collections were accompanied by images captured directly in the application, which contributed to the validation of observations made. Photographic records allowed for visual documentation of environmental conditions at the time of collection, adding quality and reliability to the data entered into the platform.

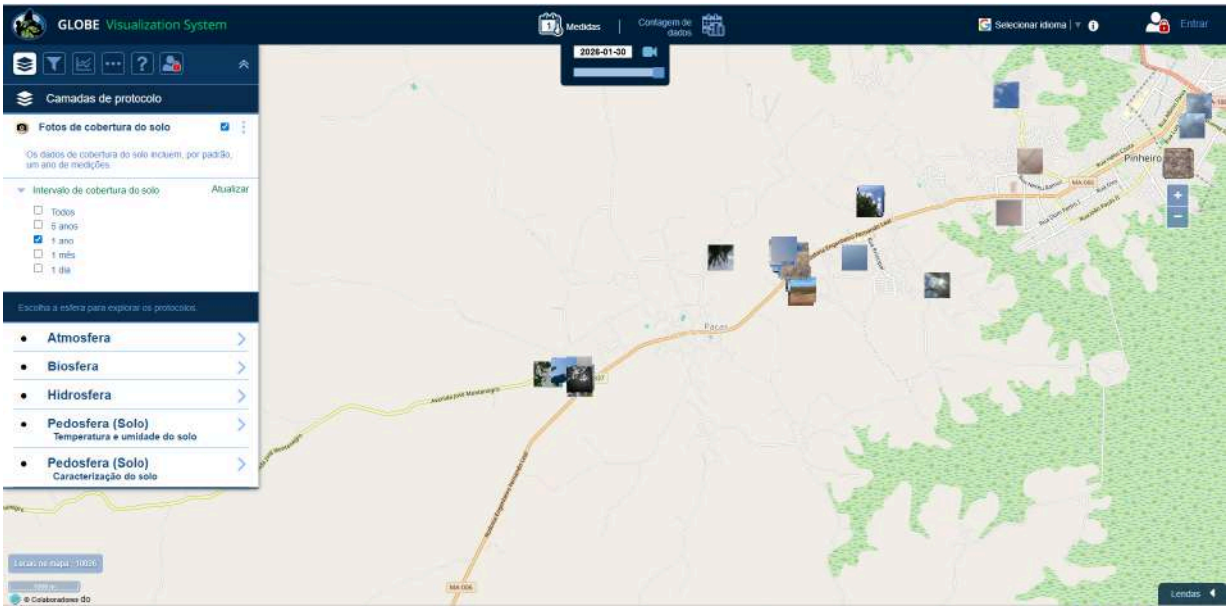
Table 2. Number of collections made by high school students using the GLOBE Observer app

CODE NAME	COLLECTIONS
	Land Cover
AlgaeAeronaut39	67
LilacExplorer40	47
VortexWandress24	45
StormScientist27	19
GO-2Z4HS	19
VortexWandress23	16
FrostObserver19	11
LilacAnalyst45	5
GO-87X18	6
SunflowerWandress53	3
GO-GE9CJ	4
FlowerObserver104	3
BeachVoyager36	4

MosquitoRobot35	1
RockObserver29	1
SnowScholar15	3
MosquitoDiver23	1
FlowerAdventurer211	0

Figure 9 illustrates the visualization of observations on the GLOBE Observer online platform, where it is possible to identify the collection points recorded by students. This visualization reinforces the insertion of data into a global database, allowing observations made at the local level to be integrated into a database used by researchers and institutions from different regions.

Figure 9. Collection points and image records obtained by students, viewed on (a) the GLOBE Observer platform and (b) Google Earth.



The comparison between the collection table (Table 2) and the website observation panel (Figure 9) highlights the effectiveness of the activity, since the records made by the students appear correctly on the project's official platform. This aspect is important because it shows that the activity was not limited to the school environment, but reached beyond the classroom, connecting students to an international scientific initiative.

5. Discussion

The results obtained reveal significant changes in land use and coverage in the municipality of Pinheiro, notably a reduction of 345.19 km² in forest formations, a decrease of 8.85 km² in savanna formations, the loss of 39.91 km² of floodplain forest, and a reduction of 15.10 km² in grassland formations between 1985 and 2024. In contrast, there was a significant expansion of pasture areas, which increased by 365.05 km² during the period, as well as growth in urban areas, with an increase of 5.95 km². Wetlands showed a different behavior, registering an increase of 107.28 km², while mangroves showed little variation, with a slight increase of 0.71 km² over the time series.

This dynamic, evidenced in analyses using data from Landsat (30 m) and Sentinel-2 (10 m) sensors, indicates the persistent predominance of forest formation in the municipal landscape, although with progressive anthropic conversion to pastures, intensified especially since 2005, reflecting processes of fragmentation and replacement of natural vegetation cover. A similar pattern is observed in regional studies, such as that by Alvim et al. (2025), which point to losses of savanna and forest formations in MATOPIBA, mainly associated with the expansion of agriculture and livestock farming. On a national scale, Souza Jr. et al. (2020) document the conversion of extensive areas of native vegetation to agricultural uses, with a strong expansion of pastures, a trend that is in line with the behavior observed in Pinheiro.

The growth of urban areas in the municipality follows recent demographic trends, intensifying pressure on natural areas and water systems, as also indicated by MapBiomas (2024) reports for the state of Maranhão. These processes reinforce the need for territorial planning and management instruments, such as the Ecological-Economic Zoning of Maranhão (ZEE-MA), aimed at mitigating environmental impacts and promoting the sustainable use of the territory. This increase may be associated with population growth and the expansion of pastures and agriculture in the Maranhão lowlands (Moro et al., 2022; Souza et al., 2020; IBGE, 2024).

In addition to spatial analyses derived from satellite images, the collection of photographic records by students using the GLOBE Observer app played an important role in understanding land use and land cover at the local scale. The photographs associated with the observations made it possible to visually document the land cover classes identified in the field, such as pasture areas, vegetation formations, wetlands, and urbanized areas. This material contributes to a better interpretation of the local landscape, serving as a qualitative complement to remote sensing data and assisting in the visual validation of the mapped classes.

From an educational and scientific point of view, image recording strengthened the practical application of the Land Cover protocol, encouraging students to critically observe landscape transformations and the impacts of human activities. The ability to view these images on both the GLOBE Observer platform and Google Earth broadened students' spatial perception by linking local collections to a global database. Thus, the photographic collections not only added quality and reliability to the data entered, but also reinforced the role of citizen science as a tool to support environmental monitoring and science education in the context of land use and land cover.

6. Conclusion

This study analyzed spatial and temporal changes in land use and land cover in the municipality of Pinheiro, Maranhão, between 1985 and 2024, based on the integration of remote sensing data and geoprocessing techniques. The results showed changes in the landscape, with a reduction in natural formations and a significant expansion of pasture and urban areas, indicating increased anthropogenic pressures on the territory over the last few decades. The use of MapBiomas data at different spatial resolutions enabled a more detailed understanding of land use dynamics, revealing conversion patterns mainly associated with agricultural activities and urban expansion. These transformations reinforce the need for continuous monitoring and territorial planning instruments that consider the environmental specificities of the Baixada Maranhense.

The incorporation of field observations made by high school students using the GLOBE Observer app demonstrated the potential of citizen science as a complementary tool to orbital analysis, especially in supporting local interpretation and visual validation of land use and land cover classes. Photographic records and georeferenced observations broadened the understanding of the spatial dynamics observed and highlighted the contribution of citizen science to environmental monitoring at the municipal level.

Finally, the study shows that the integration of remote sensing, field data, and environmental education is a promising approach for monitoring changes in land use and land cover. This strategy contributes both to the production of scientific knowledge and to the

training of more aware and engaged students, providing relevant support for sustainable environmental management and planning actions in the municipality of Pinheiro.

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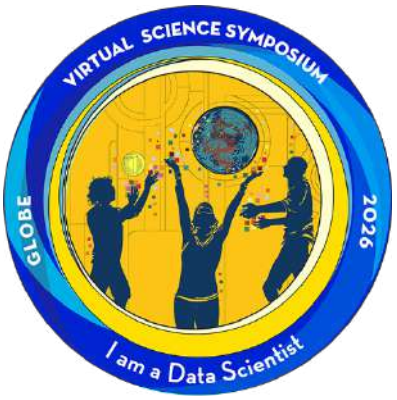
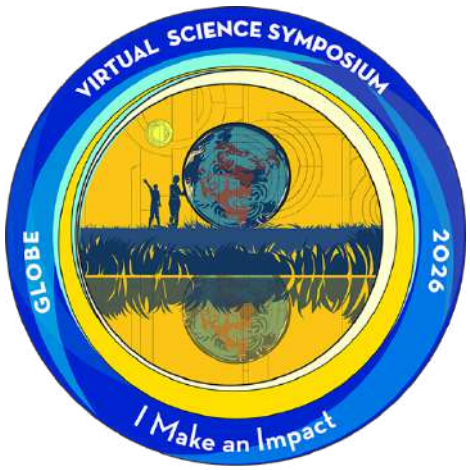
7. Badges

	The project involved collecting and organizing environmental data related to land use and land cover, obtained through field observations and georeferenced photographic records, in accordance with GLOBE Program protocols, using the GLOBE Observer application. The information was recorded in a digital environment, enabling the construction of a structured dataset on landscape characteristics and land cover classes in the municipality of Pinheiro, Maranhão. The collected data were analyzed to identify spatial patterns, local variations, and elements associated with changes in land use and land cover, allowing the interpretation of environmental processes on a local scale. Considering the limitations related to the collection period and the spatial representativeness of the observations, the project highlighted the critical and systematic use of environmental data as a complementary tool to remote sensing analyses, contributing to the understanding of the dynamics of the Earth system.

	The project was developed collaboratively with high school students enrolled in the first year of the technical course in Environment at the Federal Institute of Maranhão (IFMA), Pinheiro campus, focusing on the application of citizen science tools for recording environmental data related to land use and land cover in the municipality of Pinheiro (MA). The participatory approach integrated scientific, technological, and educational knowledge, promoting student engagement in local environmental monitoring. The students participated in all stages of the project, from training in GLOBE Program protocols to conducting field activities and systematically recording observations using the GLOBE Observer app. The initiative highlighted the potential of digital technologies and citizen science for the production of environmental data on a local scale, contributing to the strengthening of the scientific and socio-environmental education of high school students and providing support for environmental planning and sustainable land management, in addition to reinforcing the importance of student participation in environmental monitoring.



The project “Changes in land use and land cover in Pinheiro, Maranhão (1985–2024): integration between remote sensing and citizen science” was conceived based on a local demand related to the need to understand and monitor changes in land use and land cover in the municipality of Pinheiro, Maranhão, in view of the environmental transformations associated with anthropogenic activities. The initiative establishes direct connections between local issues and broader environmental challenges, especially those related to land use planning, environmental conservation, and sustainable land use planning.

The proposal contributed to strengthening land use and land cover monitoring by promoting the use of digital tools and standardized citizen science protocols through the GLOBE Observer app. The use of the application enabled the systematic recording of georeferenced observations and field images, facilitating the organization of information, increasing the reliability of the data collected, and creating conditions for integration with remote sensing databases and spatial analyses.

In the educational and social sphere, the project encouraged the active participation of high school students enrolled in the technical course in Environment at IFMA – Pinheiro Campus in citizen science practices, integrating technology, field observations, and environmental data analysis. This approach contributed to the development of scientific and technological skills, increased students' environmental awareness, and encouraged the school community's engagement in local environmental monitoring, reinforcing the role of education as a strategic tool for sustainability.

	A iniciativa teve origem na identificação de uma limitação prática relacionada ao acompanhamento e à compreensão do uso e da cobertura do solo em escala local, marcada pela dependência exclusiva de dados secundários e pela ausência de registros sistemáticos de campo. Essa condição dificulta a interpretação das transformações da paisagem, limita a validação das classes mapeadas e restringe o uso dessas informações no contexto educacional e em análises ambientais mais consistentes. Para enfrentar essa limitação, o projeto adotou procedimentos científicos associados ao estudo do uso e da cobertura da terra, combinando observações diretas em campo, registros fotográficos georreferenciados e a aplicação de protocolos padronizados do Programa GLOBE, por meio do aplicativo GLOBE Observer. A integração entre as observações de campo e a sistematização digital das informações possibilitou transformar registros pontuais em dados estruturados, passíveis de análise espacial, comparação com dados de sensoriamento remoto e interpretação das dinâmicas locais da paisagem. Como resposta prática à problemática identificada, foi utilizada uma ferramenta digital de caráter educacional voltada à coleta, organização e visualização de informações sobre uso e cobertura do solo. Essa solução contribuiu para tornar o processo de monitoramento mais acessível e consistente, ao mesmo tempo em que estimulou a autonomia dos estudantes, o uso aplicado do conhecimento científico e o desenvolvimento de uma visão crítica sobre as transformações ambientais, incentivando a busca por práticas mais sustentáveis para os desafios ambientais locais.
