Monitoring Vegetation Cover in mining areas in the municipality of Ipixuna do Pará (PA)

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Abstract:

This study focuses on analyzing the spatiotemporal dynamics of mining areas in the municipality of Ipixuna do Pará, using Planet satellite images and the Google Earth Engine (GEE) platform to monitor vegetation cover during the periods of 2016, 2018, 2021, and 2023. Data obtained through remote sensing enabled the generation of products on the Earth's surface, allowing for a detailed analysis of land use and cover changes. Using the Minimum Distance - Euclidean (MMD) algorithm in GEE, it was possible to classify and quantify the delimited areas, creating temporal maps. The analysis revealed a significant decrease in vegetation area from 2016 (41.8%) to 2018 (38.1%), with a substantial increase in 2021 (74.6%) and stability in 2023 (74.8%). The area dedicated to agriculture remained stable from 2016 (54.3%) to 2018 (55.5%) but drastically reduced in 2021 (22.0%) and 2023 (21.9%). Mining areas showed variations with an increase in infrastructure in 2021 and a consistent reduction in exposed soil areas from 2016 to 2023. The analysis emphasizes the importance of continuous monitoring and effective environmental policies to mitigate the negative impacts of mining. The results indicate that using tools like GEE is crucial for understanding land use changes and implementing environmental management strategies.

1. Introduction

The search for sustainable development has been a crucial challenge amidst increasing global environmental changes, requiring an integrated approach that considers social, economic, political and environmental sectors (Zhao et al., 2021).

In the Amazon, increasing deforestation in forests directly influences ecosystems, where it plays a central role in many of the environmental threats of our time, including global climate change, habitat degradation and species extinction (Sales; Strobl;& Elliott, 2022).

The products extracted from Remote Sensing and the various techniques for obtaining information at a global level, when combined with the tools of geographic information systems (GIS), become important data integrators, bringing with them a series of benefits for forest resource managers. who need information quickly, updated and on a large scale to assist in forest planning (Silva, 2023).

The municipality of Ipixuna do Pará, located in the northern region of Brazil, presents a complex scenario for monitoring vegetation cover due to the expansion of mining activities. Previous studies have shown that mining in the Amazon results in significant deforestation and degradation of natural habitats, which can lead to species loss and alterations in ecological processes (Fearnside, 2017). The use of remote sensing techniques, such as satellite imagery and time series analysis, has proven effective in monitoring land cover changes and assessing the impacts of mining (Gómez et al., 2018).

Furthermore, the implementation of methodologies such as LandTrendr, which allows for the detection of changes in vegetation cover over time, can provide valuable insights into the dynamics of vegetation in mined areas and aid in the development of sustainable management policies, the use of remote sensing technologies for vegetation monitoring in Ipixuna do Pará can contribute to a more detailed understanding of the impacts of mining and support the conservation of local ecosystems (Xu, 2022).

Obtaining data through the use of remote sensing allows the generation of products on the Earth's surface through the joint use of sensors, data processing equipment and data transmission equipment placed on board aircraft, satellites or other platforms, which obtain data from the recording and analysis of interactions between electromagnetic radiation and the substances that make up the imaged target (Oliveira, 2016).

Google Earth Engine (GEE) emerges as an essential platform, bringing together regional and global remote sensing data into an easily accessible computational infrastructure, facilitating the analysis and interpretation of this information (Amani et al., 2020).

Monitoring vegetation cover in mined areas is essential for assessing the environmental impacts of mining and developing appropriate recovery strategies. Mining can cause significant changes in local vegetation, affecting biodiversity as well as soil and water quality (Melo et al., 2020). In the Amazon context, where mining is a growing activity, understanding these changes is even more crucial due to the high biodiversity and ecosystem services provided by tropical forests (Federal, 2020).

Given this context, this study aims to analyze the spatio-temporal dynamics of mining areas in the municipality of Ipixuna do Pará, in the state of Pará, using Planet satellite images in conjunction with Google Earth Engine to monitor vegetation cover in periods from 2016, 2018, 2021 to 2023 for the purpose of verifying the quantity of vegetation cover loss in these areas.

2. Material and Methods

2.1 Characterization of the study area

The study area is located in the municipality of Ipixuna do Pará, as shown in Figure 1. This municipality is located in the northeast of Pará and borders the municipalities of Aurora do Pará, Capitão Poço, Nova Esperança do Piriá, Paragominas, Goianésia do Pará, Thailand, Tomé-açu and Breu Branco (Silva et al, 2023). Its territorial area is 5,145.361 km² with 67,585 inhabitants with a population whose demographic density is 13.14 inhabitants per square kilometer. Ipixuna do Pará is a municipality located in the North of Brazil, in the state of Pará, which faces significant challenges related to the expansion of mining and environmental preservation. According to the 2022 Demographic Census, Ipixuna has a population of approximately 21,000 inhabitants, distributed over an area of about 47,000 km². The local economy is heavily reliant on extractive activities, such as gold mining and timber exploitation, which contributes to the increasing pressure on the region's vegetation cover. The expansion of mining activities has led to higher rates of deforestation and environmental degradation, directly affecting the environment and the quality of life of the local population. In this context, monitoring vegetation cover in Ipixuna do Pará becomes a crucial tool for understanding and mitigating the environmental impacts of mining activities, promoting sustainability and the conservation of the region's natural resources. (IBGE, 2022).

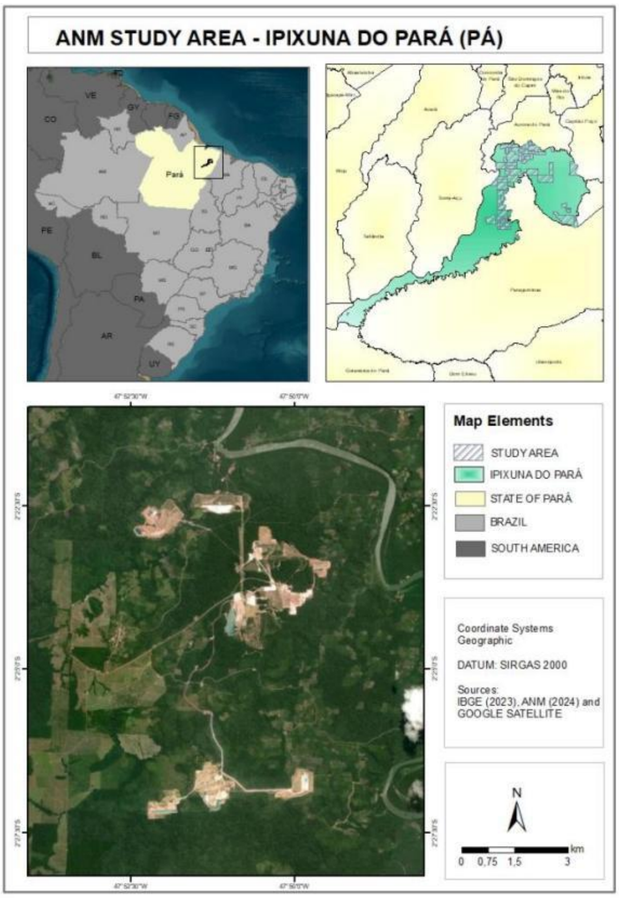

Figure 1. Location of the study area - ANM in the municipality of Ipixuna do Pará, in the State of Pará.

2.2 Methodological Procedures

To analyze this study, shapefile data were obtained from the National Mining Agency (ANM) regarding the mining areas cataloged on this platform for the municipality of Paragominas, state of Pará. In addition to data from the platform of the Brazilian Institute of Geography and Statistics (IBGE) to compose the limits of the studied municipality and generate thematic location maps of the study area. The distribution of areas of land use and coverage were defined considering the type of landscape viewed and identified using satellite images from the Planet platform, covering the period from 2016 to 2023, delimiting the mining areas into: Vegetation, Agriculture, Hydrography , Mining (Infrastructure and roads), Mining (Exposed soils) and Mining (tailings basin).

The images were classified in Google Earth Engine (GEE) using the Minimum Distance - Euclidean (MMD) algorithm. Then, using the software QGIS version 3.34 to quantify and quantify the delimited areas and subsequently create maps referring to the temporal analysis of mining areas in the municipality of Ipixuna. Statistical data was developed on the Biostats platform to be based on the quality of comparison of Precision results, obtained through the Confusion Matrix and Kappa Index, considering the data in table 1.

Kappa index classes	***Quality of Indices***
< 0,00	Terrible
0,00 – 0,20	Bad
0,20 – 0,40	Reasonable
0,40 – 0,60	Good
0,60 – 0,80	Very Good
0,80 – 1,00	Excellent

Tabela 1. Kappa index classes

And the results for the precision assessments that were carried out are summarized in table 2. The analysis showed that of all the indices analyzed, the vegetation area fell from 41.8% in 2016 to 38.1% in 2018, but increased significantly to 74.6 % in 2021 and remained stable at 74.8% in 2023. This increase may indicate environmental recovery efforts or a decrease in agricultural and mining activities. The percentage of area dedicated to agriculture remained relatively stable from 2016 (54.3%) to 2018 (55.5%), but suffered a considerable reduction to 22.0% in 2021 and 21.9% in 2023. This suggests a significant conversion of agricultural land to other forms of use, possibly for vegetation.

	2016	*2018*	*2021*	*2023*
Class Types	Precision			
Vegetation	41,8	38,1	74,6	74,8
Agriculture	54,3	55,5	22,0	21,9
Hydrography	0,9	2,3	1,0	1,5
Mining/Roads	2,4	2,3	1,0	1,5
Mining/Exposed Soil	0,2	1,6	1,8	1,5
Mining/Basins	0,3	2,4	0,5	0,2
Areas in General	16,65	16,85	16,67	16,67
Kappa coefficient	0,72	0,73	0,99	0,99

Table 2. Accuracy of the analyzed classes.

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These insights from recent studies show the importance of an integrated approach that combines detailed monitoring, environmental recovery practices and sustainability policies. They provide valuable context for interpreting land use and land cover data in mining areas, highlighting the need for continued efforts to mitigate environmental impacts and promote sustainable development.

3. Main Body of Text

The municipality of Ipixuna do Pará stands out for the diversity and richness of its mineral activities, supplying a wide range of industries. The kaolinic clay, extracted by Indústria Cerâmica da Amazônia S.A. (INCA), is essential for ceramic production in the region. Kaolin, used in various industries such as CPRM, Pará Pigmentos, Imerys, and others, is fundamental for the production of paper, plastics, and paints. Refractory clay, exploited by CPRM and Ymeris, serves the steel and glass industries due to its high thermal resistance. Bauxite, extracted by companies like Mineração Paragominas S.A. and Companhia Brasileira de Alumínio, is the primary raw material for aluminum production, a vital metal for packaging, automobiles, and aircraft. Aluminum ore, processed by Imerys Rio Capim Caulim S.A., is crucial for aluminum manufacturing. metálico. Além disso, a areia, extraída por diversos operadores locais.

Ore	*Use*	*Industries*
Kaolin clay	Industries	Indústria cerâmica da Amazônia s.a.- inca
Kaolin	Industries	CPRM, Pará Pigmentos, Imerys, Empresa Nacional de Engenharia e Empreemdimentos LTDA, Sekai Import e Export LTDA, Beraca Ingredientes Naturais LTDA, Empresa Agrícola Fluminense, Para Pigmentos, Imerys, Techidraul Comercio e Rep LTDA e Mineracao Paragominas S.A.
Refractory clay	Industres	Companhia de Pesquisa de Recursos Minerais CPRM e Imerys
Bauxite	Industries	Mineracao Paragominas s.a., companhia brasileira de Aluminio, Jose Alirio lenzi
Aluminum	Industries	Mineracao Paragominas s. e Imerys
aluminum ore	Industries	Imerys rio capim caulim s.a
Sand	Civil Construction	Angela borges da silva Elton Tavares dourado Viana, Sebastião Barbosa da silva e Andrade rodrigues areias do rio capim ltda

According to Oliveira (2024), the municipality of Ipixuna do Pará, in the state of Pará, is an important mining hub with various activities involving different minerals. For instance, kaolin clay is primarily used by the Amazon Ceramics Industry S.A. - INCA. Kaolin is also mined by several companies including CPRM, Pará Pigments, Imerys, and others, and is widely used in the production of paper and other industrial products. Refractory clay is extracted by the Companhia de Pesquisa de Recursos Minerais (CPRM) and Ymeris, while bauxite and aluminum are exploited by companies such as Mineração Paragominas S.A., Companhia Brasileira de Alumínio, and Imerys. Sand extraction, mainly used in construction, is carried out by local small business owners (IBRAM).

These mining activities are crucial for the local economy, generating jobs and promoting economic development in the region. Imerys, one of the main mining companies in Ipixuna do Pará, plays an active role in the community by conducting various social projects and distributing information to keep the local population informed about its operations and community initiatives (Carvalho, 2024).

The results for the spatial-temporal analysis of land use and coverage in the municipality of Ipixuna do Pará, are represented in Figure 2 e Table 2, where it was possible to evaluate and quantify the changes in the periods of 2016, 2018, 2021 and 2023. The analysis of these changes is crucial to understanding the processes of urbanization, deforestation, agricultural expansion and other human activities that impact the environment.

The vegetation area decreased from 2016 (479.73 km²) to 2018 (436.22 km²), but showed a considerable increase in 2021 (855.38 km²) and remained stable in 2023 (857.70 km²). This increase can be interpreted as a forest recovery or a reclassification of vegetation cover data. The area allocated to agriculture remained relatively stable between 2016 (622.33 km²) and 2018 (636.45 km²), but suffered a drastic reduction in 2021 (252.25 km²) and remained practically the same in 2023 (250.98 km²). This reduction may be the result of conservation policies, changes in land use, or increasing urbanization and the area of water bodies increased from 2016 (10.83 km²) to 2018 (26.26 km²), decreased in 2021 (11.96 km²) and increased again in 2023 (16.85 km²). Fluctuations can be attributed to seasonal changes, extreme weather events, or human interventions such as the construction of dams and canals.

It was also observed that areas related to mining infrastructure decreased from 27.97 km² in 2016 to 17.99 km² in 2018, showed a slight increase in 2021 (20.19 km²) and decreased again in 2023 (17.26 km²). The area of soil exposed by mining has consistently decreased from 1.98 km² in 2016 to 0.94 km² in 2023. And the area of mining basins has shown a significant increase from 3.58 km² in 2016 to 27.66 km² in 2018, followed by a reduction in 2021 (5.59 km²) and 2023 (2.69 km²).

	2016	*2018*	*2021*	*2023*
Class Types	Km²			
Vegetation	479,73	44,36	855,38	857,70
Agriculture	622,33	636,45	252,25	250,98
Hydrography	10,83	26,26	11,96	16,85
Mining/Roads	27,97	17,99	20,19	17,26
Mining/Exposed Soil	1,98	1.83	1,07	0,94
Mining/Basins	3,58	5,59	5,59	2,69
Areas in General				

Table 2. Classes per square kilometer (Km²).

According to Oliveira (2019), mining activity plays a significant economic role in the state of Pará, resulting in a flow of goods and products that not only trigger social conflicts in the region, but also contribute to deforestation, contamination of waterways surfaces and the obstruction of springs.

According to studies by Santos (2021), the vegetation area in the municipality of Ipixuna do Pará suffered a reduction of approximately 24 km² in the period from 1991 to 2021. On the other hand, pasture areas increased significantly, with an increase of around 17 km². Mining areas also showed a significant increase, due to the exceeding the carrying capacity of mining dams over the years. There was an increase in water bodies, although less significant, with an increase of around 0.2 km². This increase may have caused confusion in class classification, as some liquid waste can be confused with water bodies.

Monitoring vegetation cover in mining areas is crucial to understanding environmental impacts and promoting the sustainable recovery of degraded areas. Mining, especially in tropical regions such as the Amazon, causes significant changes in vegetation, resulting in deforestation and manipulation of ecosystems (Melo et al., 2020). In particular, the municipality of Ipixuna do Pará faces challenges related to the expansion of mining activities, which worsen the loss of vegetation cover and compromise ecosystem services (Ferreira et al., 2023).

However, these studies were equivalent to an area polygon in the analysis of changes in land use and coverage in the municipality of Ipixuna, in the state of Pará, where a significant increase in mining areas within the studied polygon was evident. This growth is related to the overcoming of the carrying capacity of mining dams throughout the anos. This differs from the general study related to mining areas in this study.

Still, it highlights the need for continuous monitoring and effective environmental policies to mitigate the negative impacts associated with mineral exploration. Furthermore, the class confusion caused by the increase in liquid waste reinforces the importance of more precise classification and environmental management strategies that guarantee the sustainability of local water resources.

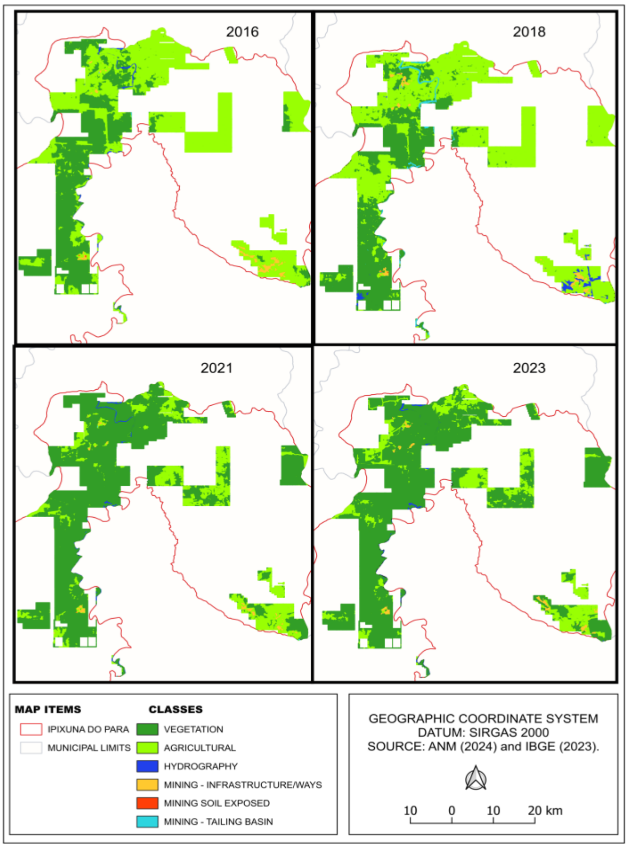

Figure 2. Classification of land use and coverage in the years 2016, 2018, 2021 and 2023 in the municipality of Ipixuna do Pará, State of Pará.

Lima et al. (2022) analyze how mining activity impacts vegetation cover in Amazonian regions. The study highlights that mining results in significant loss of biodiversity and soil degradation, as seen in the reduction of vegetation areas and the increase in areas of exposed soil between 2016 and 2023. The continued decrease in the area of exposed soil of 1.98 km² in 2016 to 0.94 km² in 2023 suggests revegetation and soil recovery efforts after mining, aligning with the study's observations.

Castro et al. (2023) explore the use of remote sensing technologies to monitor the expansion of mining areas and their impacts on land use. Using tools such as Google Earth Engine allows detailed, real-time analysis of changes in land cover, facilitating the identification of mined areas and helping to plan mitigation actions. This is crucial to understanding fluctuations in road and exposed soil mining data.

Another relevant point in the diagnosis of mining areas in the municipality of Ipixuna is the notable transformation of its landscape over time. A significant increase in pasture areas was observed until 2018, while, on the other hand, there was a reduction in mining areas, structures/roads, exposed soil and tailings basins. It is worth mentioning that tailings basins generated class confusion due to their similarity to water bodies.

Based on the classification of land use and coverage in mining areas using Google Earth Engine, it was possible to highlight the importance of monitoring in identifying vegetation areas present in this region. Furthermore, the efficiency of the images in detecting changes that occurred in the analyzed periods was positively evidenced in the analyzed classes. Therefore, it is essential to carry out more in-depth studies to obtain more accurate results and implement management strategies with responsible, participatory and efficient management that involves the planning, execution and evaluation stages.

The use of remote sensing technologies has proven to be an effective tool for monitoring vegetation cover and assessing the impacts of mining. Satellite imagery and time series analysis techniques such as LandTrendr allow detailed observation of changes in land cover over time (Cohen et al., 2020). These methodologies are essential for the early detection of changes in vegetation and for the implementation of environmental management and recovery strategies (Gómez et al., 2018).

The literature highlights the importance of continuous monitoring to mitigate the negative impacts of mining. Recent studies show that the recovery of vegetation cover in mined areas is possible with the application of appropriate revegetation and soil restoration techniques, which contribute to the recovery of affected ecosystems (Ferreira et al., 2023).

Ecological restoration is a science aimed at initiating or accelerating the recovery of ecosystems that have been degraded, damaged or destroyed by direct or indirect human actions. The main objective is to reestablish ecosystem services. Ecological restoration can also be described as an activity aimed at recovering the flows of natural goods and services that ecosystems provide to society (Oliveira, 2021).

Final considerations

In addition to its role as a vital mining hub, Ipixuna do Pará faces the critical challenge of balancing economic development with environmental conservation, particularly regarding vegetation cover. The monitoring of vegetation cover through remote sensing technologies plays a pivotal role in this effort, providing valuable insights into the impact of mining activities on local ecosystems.

Effective monitoring allows for timely assessments of vegetation loss and changes in land use patterns, facilitating informed decision-making to mitigate environmental impacts. It is imperative to implement rigorous monitoring protocols and leverage remote sensing data to ensure sustainable development practices. This approach not only safeguards the biodiversity and ecological balance of the region but also promotes the long-term viability of mining operations in harmony with nature.

Furthermore, fostering collaboration between mining companies, local communities, and environmental agencies is essential for implementing comprehensive strategies that prioritize environmental conservation while fostering socio-economic development. By integrating remote sensing technologies into environmental management frameworks, Ipixuna do Pará can navigate the complex dynamics of economic growth and environmental stewardship, ensuring a resilient and sustainable future for generations to come.

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