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Advancement of urban development and regularization of consolidated occupations on the margin of an artificial reservoir through spectral indexes

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Authors' notes'

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Abstract

Objective: The purpose of this study is to measure urbanization and consequent suppression of native vegetation on the banks of artificial reservoir of Miranda Hydroelectric Power Plant (HPP) in Uberlândia, Minas Gerais (MG), Brazil, resulting from the spread of clandestine and irregular subdivisions.
Method/Approach: Quantitative research, with the application of Digital Image Processing (DIP) techniques, Normalized Difference Vegetation Index (NDVI) and Normalized Difference Built-Up Index (NDBI) on the banks of Miranda HPP.
Results and Conclusion: The results confirmed the urbanization of land division (regular or irregular) for housing purposes and recorded the evolution in the loss of areas with vegetative vigor (natural, agricultural or pasture). NDVI established the accuracy as a methodology for environmental analysis, while NDBI demonstrated failures to differentiate the spectral responses of anthropization.
Research implications: The urbanization of rural areas through the regularization of consolidated occupations promotes urban sprawl, real estate speculation and high cost for urban management.
Originality/value: On the banks of HPPs, urbanization gradually transforms land use in rural areas with land division, which contributes to an increase in environmental impacts. The application of DIP techniques and NDVI and NDBI indexes confirmed their effectiveness as low-cost tools in public management and monitoring of environmental impacts.

Keywords: urbanization, rural areas, artificial reservoirs, geotechnologies.

Avanço do desenvolvimento e da regularização urbana de ocupações consolidadas na margem de um reservatório artificial por meio de índices espectrais

Resumo

Objetivo: A proposta deste estudo é mensurar a urbanização e a consequente supressão de vegetação nativa às margens do reservatório artificial da Usina Hidrelétrica (UHE) de Miranda, no município de Uberlândia, Minas Gerais, Brasil, oriundas da disseminação de loteamentos clandestinos e irregulares.
Método/Abordagem: Pesquisa de caráter quantitativa, com a aplicação de técnicas de Processamento Digital de Imagens (PDI), dos índices de áreas verdes (NDVI) e construídas (NDBI) às margens da UHE Miranda no município de Uberlândia.
Resultados e Conclusão: Os resultados confirmaram a urbanização do parcelamento do solo (regular ou irregular) para fins habitacionais e registraram a evolução na perda de áreas com vigor vegetativo (natural, de agricultura ou pastagens). O NDVI confirmou a acurácia como metodologia para análises ambientais, enquanto NDBI demonstrou falhas para diferenciar as respostas espectrais da antropização.
Implicações da pesquisa: A urbanização de áreas rurais por meio da regularização de ocupações consolidadas promove o espraiamento urbano, a especulação imobiliária e elevados custos para a gestão urbana.
Originalidade/valor: Às margens de UHEs, a urbanização transforma paulatinamente o uso do solo em áreas rurais com o parcelamento do solo o que contribui para o aumento de impactos ambientais. A aplicação de técnicas de PDI e dos índices NDVI e NDBI confirmou a eficácia como ferramentas de baixo custo na gestão pública e monitoramento dos impactos ambientais.

Palavras-chave: urbanização, áreas rurais, reservatórios artificiais, geotecnologias.

Avance del desarrollo urbano y regularización de ocupaciones consolidadas al margen de un embalse artificial mediante índices espectrales

Resumen

Objetivo: La propuesta de este estudio es medir la urbanización y la consiguiente supresión de la vegetación nativa en las márgenes del embalse artificial de la Usina Hidroeléctrica (UHE) Miranda en el municipio de Uberlândia, Minas Gerais, Brasil, resultante de la expansión de fraccionamientos clandestinos e irregulares.
Método/Enfoque: Investigación cuantitativa, mediante la aplicación de técnicas de Procesamiento Digital de Imágenes (PDI), los índices de área verde (NDVI) y construida (NDBI) en las márgenes de la UHE Miranda en municipio de Uberlândia.
Resultados y Conclusión: Los resultados confirmaron la urbanización de la división del suelo (regular o irregular) para fines habitacionales y registraron la evolución en la pérdida de áreas de vigor vegetativo (natural, agrícola o de pastoreo). NDVI confirmó su precisión como metodología para el análisis ambiental, mientras que NDBI demostró fallas para diferenciar las respuestas espectrales de la antropización.
Implicaciones para la investigación: La urbanización de las zonas rurales mediante la regularización de ocupaciones consolidadas promueve la expansión urbana, la especulación inmobiliaria y los altos costos de gestión urbana.
Originalidad/valor: A orillas de UHEs, la urbanización transforma gradualmente el uso del suelo en las zonas rurales a través de la división del suelo, lo que contribuye a un aumento de los impactos ambientales. La aplicación de las técnicas PDI y de los índices NDVI y NDBI confirmaron su efectividad como herramientas de bajo costo en la gestión pública y el monitoreo de impactos ambientales.

Palabras clave: urbanización, zonas rurales, embalses artificiales, geotecnologías.

Introduction

Awareness about the pressures suffered by the environment has been discussed for decades by scholars and governments at world meetings and conferences, since Stockholm in 1972 and more recently at 26th Conference of Parties (COP26) of United Nations (UN). According to Greenhouse Gas Emissions Analysis Report and their Implications, developed by Greenhouse Gas Emissions and Removals Estimation System (2023), with an initiative of Climate Observatory, data collected from 1970 to 2021 has shown that land use changes accounted for 49% of gross greenhouse gas emissions in the country in 2021, compared to 46% in 2020.

Updated data by MapBiomas Brazil (2020), a multi-institutional initiative evolving universities, Non-Governmental Organizations (NGOs) and technology companies focused on monitoring transformations in land cover and use in Brazil, show loses of 87.2 million hectares (Mha) in native vegetation areas from 1985 to 2019, which is equivalent to 10,25% of national territory. Among the six Brazilian biomes (Amazon, Atlantic Fore, Pampa, Pantanal, Caatinga and Cerrado), the last one was the most affected, with less than 28.5 Mha, which represents 21.3% of total losses related to changes in land use for agricultural activities between pastures and temporary and perennial crops. It should be noted that 66.8% of the country is covered by native vegetation, without indicating preservation; and 9.3% is secondary, with areas cleared and converted for human use at least once.

The increasing index denotes an elevation in deforestation and, despite Brazil having met the numerical target established in National Policy on Climate Change, its emissions trajectory and the pollution profile due to deforestation were not changed (Greenhouse Gas Emissions and Removals Estimation System, 2023). According to the Annual Deforestation Report (ADR) on MapBiomas website, the deforested area in Brazil grew 22.3% in 2022, while 90% of the deforestation in the country is observed in Amazon and Cerrado biomes and derives from illegality (MapBiomas Brazil, 2023), mainly concerning agricultural, extractive or livestock activities – it reinforces the importance of preserving natural heritage to maintain the balance between how much is vandalized and subtracted from the environment. However, the spread of land subdivisions for residential purposes or not – such as conventional subdivisions (modality commonly seen in urban areas) often close to Permanent Preservation Areas (PPAs) – has removed the native vegetation in rural areas, with inadequate occupation standards without respecting urban planning and environmental legislation, as they are implemented and sold clandestinely.

In rural areas of Uberlândia (MG), where previously there was a mosaic of farms in larger (glebes) or smaller areas (rural modules) with activities aimed at the first and second sectors of society (agropastoral and industrial), in the last decade, the land division and alienation of lots with urban characteristics, that is, in small parcels (lots), are observed. It especially occurs through purchase and sale contracts in notary offices in ideal fractions, an alienation of land curbed only in recent years, with the interference of Public Prosecutor's Office.

According to information obtained from the Uberlândia City Hall (UCH) portal, there are currently 17 subdivisions in urban zone and 146 in rural zone, with an irregular situation – on the last ones, 38% are located on the banks of Miranda Hydroelectric Power

Plant (HPP) dam. With the advent of Federal Law (FL) no. 13.765 (2017) to regularize informal urban centers, Uberlândia (MG) had transformed a 1.5 km strip along the banks of artificial reservoir of Miranda HPP dam, called Specific Urbanization Zone 5 (SUZ 5), on the banks of Uberabinha and Araguari Rivers, from a rural to an urban area, which enabled the regularization of several illegal subdivisions that had already been established in the region.

The urbanization of rural areas, especially on the banks of HPPs, bring about the loss of biodiversity, soil sealing, generation and carrying of solid waste into the dam, *inter alia*. In this context, the research proposes, based on a time frame delimited by regulations that established mandatory minimum ranges of environmental preservation between 2000 and 2019 and a geographical frame – a section of SUZ 5 comprising the upstream quota (border between Uberaba and Uberlândia) and downstream level (spillways) of Miranda HPP – to use Digital Image Processing (DIP) techniques, more specifically spectral indexes, in diagnosing the suppression of native vegetation in and out the PPA. Surveying soil use and coverage through traditional techniques would be time-consuming and costly, given the size of the area; however, satellite images and DIP techniques have been widely used, because they cover larger areas at a lower cost in the survey stage.

Among the PDI techniques, the Normalized Difference Built-up Index (NDBI) and the Normalized Difference Vegetation Index (NDVI) stand out for their variety of applications in use studies and soil cover, whose interests refer, respectively, to the area with buildings or vegetation, which are even capable of capturing the size of vegetation through the color intensity. In addition, the evolution of suppression of native vegetation was mapped through the NDVI and increase in area built by the NDBI, recording the advance of anthropization in SUZ 5, which confirmed the loss of areas of vegetative vigor (natural, of agriculture or pastures) and the increase in land division (regular or irregular) for housing purposes.

Theoretical framework

From the perspective of land use or the economic activities that characterize the city, Souza (2005) defines it as a space for production, commerce, and services. In the meantime, the growing search for satisfaction of basic and (im)material human needs to drive its dynamics, materializing in accordance to the desires of various actors and the dominant forces that outline the urban fabric according to their interests – here, the relation between human beings is dissociated from nature and pressurizes it.

Concerning the dynamics and pressures under municipalities, Gonçalves (2010) cites the creation of a demand treated by speculator capital without any responsibility or concern for spaces that can contribute to a better quality of life in the city. This subtle dynamic goes unnoticed on a daily basis, managed by the strength of those who hold the resources such as property of the land or investments to undertake it, assisted by supervisory bodies or legislators who only see the municipality and its expansion from the perspective of legislation and the present moment.

In the established discourse of urban projects, Magalhães (2006) emphasizes that environmental issue is not inserted in the core of concerns. Accordingly, Jacobs (2003) points that this attention is considered in accordance to providing open areas in urban spaces. With the desire for life and environmental quality, the expansion of cities should offer sustainability and equity how spaces are produced and appropriated.

The risk of environmental degradation is related to anthropized impact and, in this sense, urbanization, from the moment of presenting an urban planning project, should offer solutions that foresee the risks because, when developing subdivisions and expanding cities, a way of occupying the territory is proposed, with social relations and consequently environmental impacts (Farr, 2013). Jacobi (2004) adds that most urban environmental risks are within the sphere of municipal competence, because this public entity establishes regulations regarding the use and occupation of land that impacted the appropriation mode and, consequently, environmental preservation.

Regarding the importance of regulations, Mello (2005) explains that water bodies' banks protected by PPAs are a legal mechanism created to support environmentally vulnerable areas, in which the principle of intangibility is embedded, with the prohibition of any form of use and occupation. In the case of geographical area proposed for the research, the PPA that surrounds banks of an artificial reservoir is the stage and object of ambiguities and dualities, as it is an attractive place for various uses and leisure/recreational activities – at the same time, it constitutes a place of environmental preservation.

Notoriously, the preservation of native vegetation (or PPA strips), among other objectives, protects watercourses and fauna, prevents silting, contamination and eutrophication of water sources, guarantees the efficient retention and absorption of rainwater by the soil and optimizes air quality (Pessoa, 2014). Meanwhile, the impacts caused by the implementation of a HPP are the flooding of food production areas and forests, climate change and interference in the immigration of fauna species and reproduction of ichthyofauna (Silva, 2011).

Urban expansion in rural areas, such as the object of this study, produces negative impacts on forests, pastures, and agricultural areas. Compact and dense cities oppose expansion and vectors of economic development, which result the modification on the usage of previously unurbanized areas that could provide a “natural habitat”. By the way, urbanized areas have a high *per capita* cost on natural systems and habitats through urban improvements in soil sealing, whether with buildings or paved roads, increased water use and energy demand (Farr, 2013).

Due to the difficulties faced by public authorities in monitoring the vast dimensions of a municipality, remote sensing becomes an excellent cost-benefit tool for environmental monitoring and consolidated urban occupations. According to Menezes and Fernandes (2013), geotechnologies are determined by a set of software, products and techniques, such as Geographic Information Systems (GIS), remote sensing, Global Navigation Satellite Systems (GNSS), numerical terrain models and database organization.

Teixeira and Rizzatti (2022) affirm that the application of geotechnologies in spatial data permits monitor and quantify areas, objects and/or phenomena of interest. In this way, the combination of data collected through remote sensing, in the form of images, with an application of DIP techniques, allows the quantification and analysis of environmental episodes, generating results that guide future actions or resolution of environmental conflicts, to reevaluate the decisions made for urban and environmental cities planning (Morandi et al., 2018).

Among the spectral indexes, NDVI and NDBI are used for studies involving environmental and urban themes and provide data at relatively low costs and in a short time, allowing precise diagnoses or adaptation of economic development, environmental protection, or city management strategies. Researches on PPAs in the Brazilian Cerrado show that satellite images and computational tools can be used to monitor patterns of change in biodiversity caused by anthropized actions, which facilitates decision-making and helps management, prevention and land-use planning strategies (Moreira et al., 2015; Oliveira, Borges, & Acerbi Júnior, 2018). Among the various DIP techniques implemented in the information extraction process are the NDVI and NDBI spectral indices for environmental and urban issues investigations and providing data at relatively low cost and in a short time, allowing for more accurate diagnoses or adaptation of strategies for economic development, environmental protection or city management.

Projected by Rouse et al. (1973), NDVI has been used to compare changes in vegetation covering over time, as it is less influenced by variations in atmospheric conditions; and NDBI, created by Zha, Gao and Ni (2003), has a great applicability in identifying urban areas and monitoring spatial distribution and urban expansion. According to Saraiva et al. (2012), NDVI explores the differences between spectral responses in the Near Infrared (NIR) and spectral behavior of vegetation. In turn, NDBI, also known as built-up, explores the differences in spectral responses of urban and non-urban areas between Medium Infrared (MIR) and NIR.

Material and methods

This research indicates the damming surroundings of Araguari River, formed with the implementation of Miranda HPP, bordered with the municipalities of Indianópolis and Uberlândia (MG), as an integral part of a series of plants, including Nova Ponte, Amador Aguiar I and Amador Aguiar II HPPs. The methodology was applied on the dam banks in Uberlândia (MG).

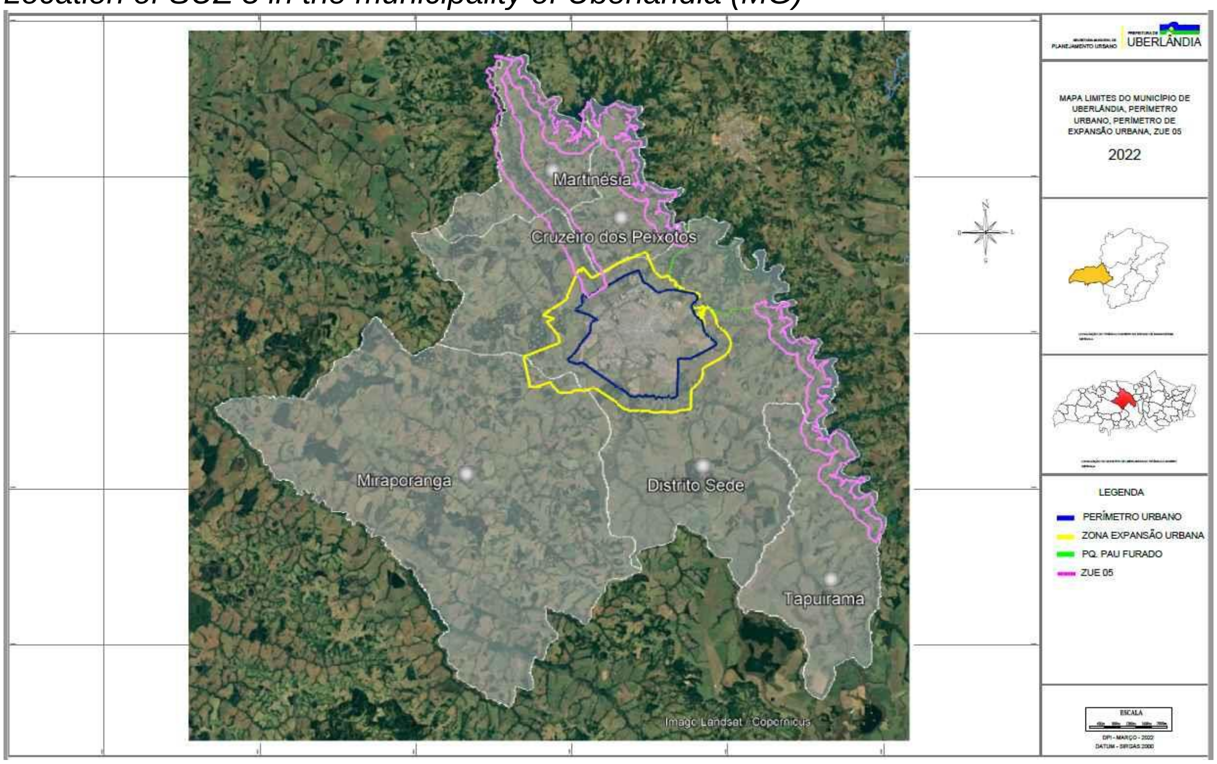
Contextualization and characterization of the study object

The artificial reservoir formed with the implementation of HPP Miranda begins at coordinates 19°02’57” S / 47°59’38” W upstream on the border between Uberaba and Uberlândia (MG); and 18°54’44” S / 48°02’12” W downstream where the spillways are located. Net generation is approximately 105.8 Gigawatt/hour (GWh) during rainy season and 76.5 GWh on dry period.

Therefore, HPP Miranda is officially domiciled in Indianópolis (MG), located on the 23rd zone. However, the 22nd zone will be used to develop the research, as it is restricted to the margin of Miranda HPP in Uberlândia (MG). The reference system used was SIRGAS 2000, with Universal Transversal Mercator (UTM) coordinate system projection in the zone 22° S. The geographical area defined to apply the chosen methodology was delimited in the stretch of dammed area of Araguari River, since Uberaba and Uberlândia (MG) upstream and the dam spillways downstream (Figure 1).

Figure 1

Location of SUZ 5 in the municipality of Uberlândia (MG)



Source: Uberlândia City Hall (2023).

The FL no. 13465 (2017) sets up the regularization of land tenure in irregular and clandestine subdivisions in both urban and rural zones, with two distinct categories of classification of these properties subject to regularize properties with characteristics of low-income population and, therefore, of social interest (REURB-S) and its properties with specific characteristics that cannot be classified as of social interest (REURB-E). It is affirmed that regularization of illegal subdivisions on the banks of the Miranda HPP is classified as Reurb-E.

In the meantime, Complementary Law (CL) no. 671 (2019) was implemented in Uberlândia (MG) to modify the category of land around Miranda HPP from rural to urban within a 1.50 km strip from the flood level along Uberabinha River and entire bank of Araguari River, except for Parque do Pau Furado and Zona de Amortecimento do Pau Furado, to the extreme southeast of the municipality (SUZ 5), in a region called “Interlagos Tourist Complex”.

Materials

The materials applied to develop the research were: 1) satellite images, obtained free of charge from National Institute for Space Research (NISR) website; 2) vector files of HPP Miranda provided by Engie, from the planimetric survey of the bank in Uberlândia (MG), in Miranda reservoir. A geographical area was defined within 1.50 km range established by CL no. 671 (2019), which defined SUZ 5 in the referred municipality, more specifically the banks of Miranda HPP.

Regulations selected to obtain the ranges related to PPAs and SUZ 5 to define polygons to be worked in the maps were obtained from portals for federal[1] and municipal[2] laws on internet. The polygon of 1.50 km strip established by SUZ 5 was obtained from Directorate of Geographic Information, from the Urban Planning Directory (DGI/UPD) of UCH, and the PPA polygon, for the case of the dam, through the concession company Engie Brazil.

Methods

For the time frame, the chosen years were 2000 (beginning of operation of Miranda HPP), 2008 – year established by the former Forest Code (FC), in which the range of the PPA for artificial reservoirs licensed until 2008 was inserted between maximum normal operating quota and maximum quota maximorum; December 12th, 2016 – cutoff date

[1] Retrieved from https://www4.planalto.gov.br/legislacao

[2] Retrieved from https://leismunicipais.com.br/prefeitura/mg/uberlandia

established by FL no. 13,675 (2017), to consolidated urban centers be benefited and regularized; and 2019 – creation of CL no. 671 (2019), which establishes SUZ 5 in which the previously rural land becomes urban with a change in urban parameters and begins to admit in this region, in addition to the land division for housing purposes, commercial, services and industrial uses.

In each period chosen as a time frame, polygons were delimited that converge with past and current regulations to quantify vegetative vigor in the respective years overlapped in 1.50 km band established by SUZ 5. Polygons of PPA ranges within SUZ 5 were implemented in accordance with regulations of each year with two dates being chosen prior to the current FC – FL no. 12,651 (2012) – and other two periods after this document, namely: a) 2000 and 2008 – polygons of former FC (1965), with 100 meter range for rural areas; b) 2016 – polygons of Brazilian National Environmental Council (CONAMA, in Portuguese abbreviation) Resolution no. 302 (2002), for rural areas (100 meter range), and FC (2012), with 30 meter range; c) 2019 – Conama Resolution no. 302 (2002), with polygons for urban areas with 30 meter range and FC (2012). From the current FC (2012), PPA range would only be the range comprised between the normal operating level (+676.00) and the maximum maximorum level (+676.95), around the HPP Miranda dam.

The satellite images selected and processed to generate NDVI and NDBI maps comprehend the dry period between July and September and they are based on Landsat 5 satellite, TM sensor (Table 1), from 2000 to 2008, and Landsat 8, OLI sensor (Table 2), from 2016 to 2019. Specifically, the Red, Near Infrared and Medium Infrared bands were applied, with a spatial resolution of 30 meters and radiometric resolution of eight and 16 bits, respectively. The processing of satellite images was carried out using the ENVI 5.2 Classic software, 64-bit version, at the Geoprocessing Laboratory of the Institute of Geography (IG) at UFU. The maps generated were overlaid using the free software QGIS, installed in the same laboratory, to develop the maps on the chosen dates.

Definition of bands for applying NDVI and assessment classes

To calculate NDVI, bands 3 and 4 were used, referring to 2000 and 2008, from the TM sensor (Landsat 5) and, for 2016 and 2019, bands 4 and 5, from the OLI sensor

(Landsat 8) and NDVI index values. According to images, the following values were extracted, in order to obtain the classes of interest, processed in the free software QGIS: i) dense vegetation: NDVI >/= 0.5; ii) growing vegetation: 0.2 </= NDVI < 0.5; iii) exposed soil/anthropized zone: -0.2 </= NDVI < 0.2; iv) others: NDVI < -0.2.

After the processing result, which is given in shades of gray, the image properties were changed to the simple false-color band, still in QGIS. The colors expressed in each class are demonstrated dividing it into two classes/colors of what is “dense vegetation” and “growing vegetation – forage/pasture/cultivation”. For the “exposed soil” class, the assumption was adopted that vegetation was removed and, therefore, it is an anthropized area, included in the same class.

Definition of bands for applying NDBI and assessment classes

NDBI calculation was performed with bands 4 and 5 of TM sensor (Landsat 5), which correspond to NIR and MIR, respectively, using images captured from 2000 to 2008. However, due to a failure in TM sensor in 2013, on the period from 2016 to 2019, spectral bands 5 (NIR) and 6 (MIR) captured by OLI sensor (Landsat 8) were used to calculate NDBI.

As the segmentation method for each area may vary according to the predominance of the material used in civil construction, method was calibrated using the urban area of Uberlândia (MG) as a reference, which guided the quality definition of the classification. In this way, the classes were adjusted until the areas of possible subdivisions present in the studied region and were clearly obtained in the following way: i) anthropized area = ≥ 0.5; ii) non-anthropized area = < 0.5.

Results and discussion

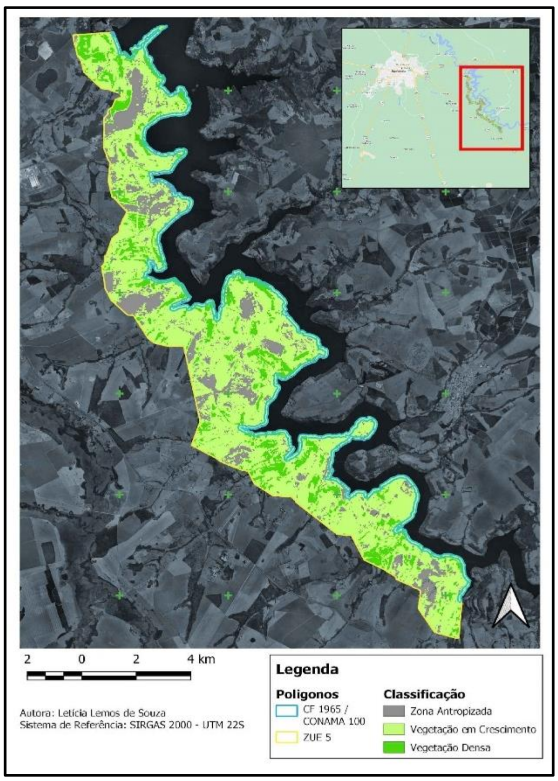
The achieved results reflect the reality on site and record the loss evolution of vegetated areas and the urbanization advancement, due to the existence of illegal subdivisions to be regularized according to the facts that add up chronologically: 1) as a result of decrease in width of the preservation ranged set out in FC (2012), it is established that PPA range on the banks of artificial dams would be limited to the horizontal projection between normal maximum operational quota and maximum maximorum quota; 2) the advent of FL Regularization Law no. 13,465 (2017); 3) because of the creation of CL no. 671 (2019), which established SUZ 5 and transformed rural into urban land along a 1.50 km strip.

NDVI

The number of anthropized areas in anthropized zone, in relation to the former FC (1965)/Conama 100 polygon area, corresponds to 1.20% of entire study area. From 2000 to 2008, there was a reduction in the anthropized area (1.20% to 1.03%). Regarding growing vegetation, it corresponds to an average of 5.90% of total area. Such as the behavior of anthropized zone, the area with growing vegetation experienced a certain decline directly associated with an appearance of dense vegetation (Figures 2 and 3).

Figure 2

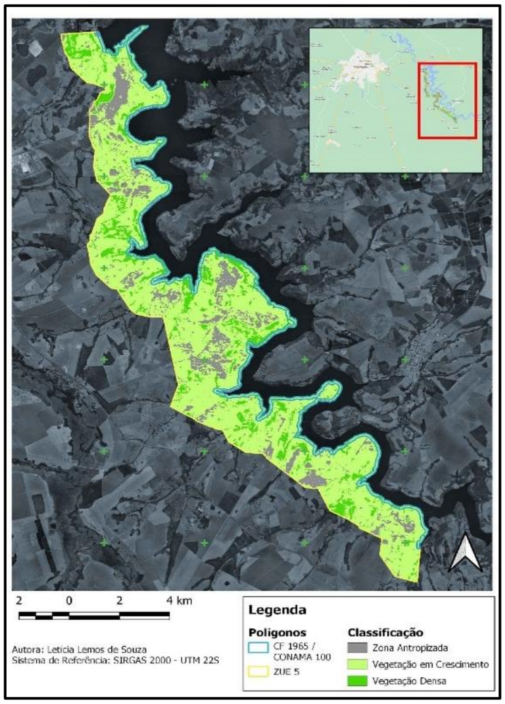
NDVI classification – 2000



Source: Author’s data (2023).

Figure 3

NDVI classification – 2008



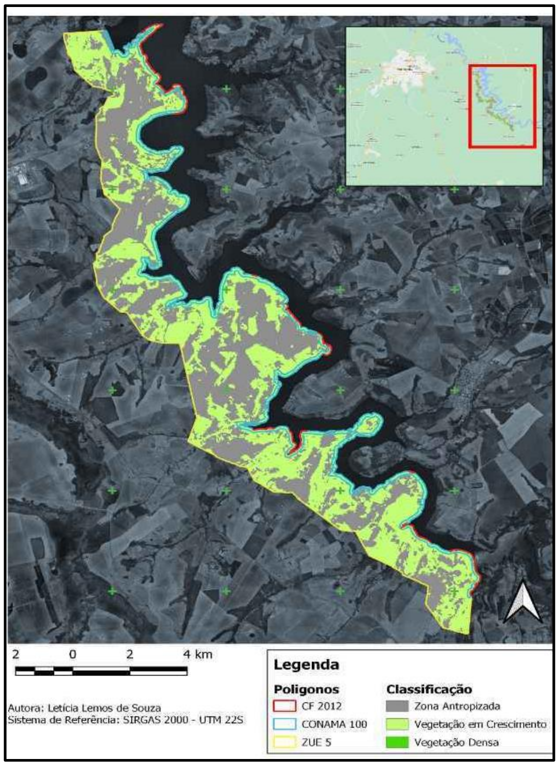
Source: Author's data (2023).

Dense vegetation, which corresponds to only 1.78% in 2000 and 1.95% in 2008, represents the highest density, whether with low vegetation in large volume and/or the presence of large vegetation with significant density. It had a relative increase from 2000 to 2008, which indicates a relevant sign, considering that local vegetation probably recovered in a natural way. The results indicate a reasonable stability between removal of vegetation and its recovery, with a general effect of improvements in the environmental quality of the region.

In this interim, the area corresponding to FC (2012), which comprises the smallest portion in relation to the entire area analyzed, equivalent to only 0.19% of it, the area relates to a zone destined for full protection of the region's flora and fauna. As a small area, it will be in considerably greater state of preservation in parallel with other areas. At percentages of anthropized zones, there was a relative increase in these values – from 0.053% in 2016 to 0.56% in 2019, probably derived from some specific interventions in FC (2012) area (Figures 4 and 5).

Figure 4

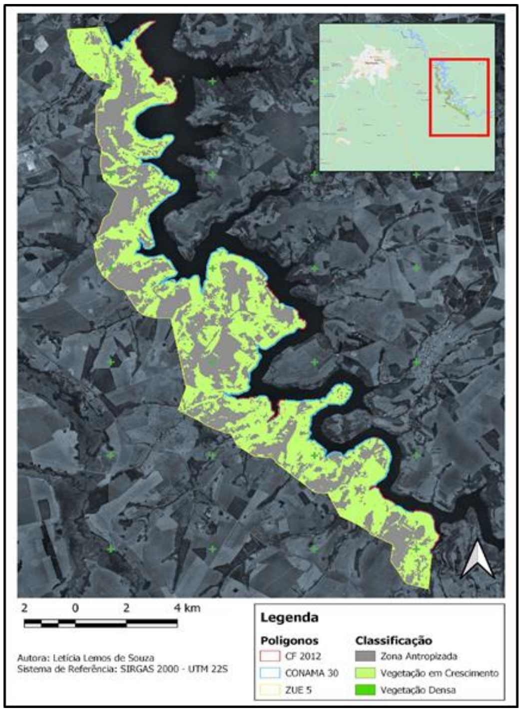
NDVI classification – 2016



Source: Author's data (2023).

Figure 5

NDVI classification – 2019



Source: Author's data (2023).

The growing vegetation went from 0.156% to 0.153% and indicates a direct relationship of compensation for the vegetation area suppressed to carry out the human interventions performed in the analyzed area. It was not identified any region of dense vegetation in the analyses conducted for those years – for this reason, they will not be mentioned in the corresponding verifications.

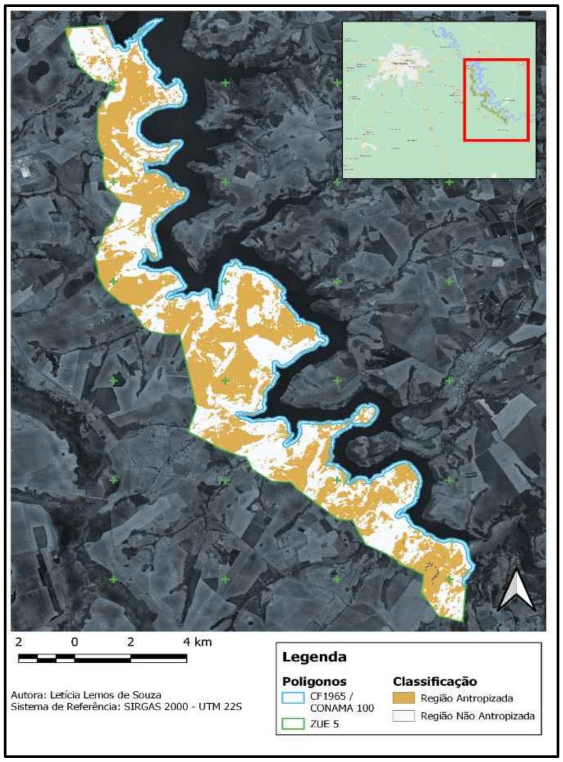
NDBI

NDBI classification index is not a selective method regarding the identification as an anthropized zone; so, regions with dry vegetation, among other places with similar spectral responses, are commonly identified with a spectral return similar to houses and buildings.

These regions are still anthropized ones; however, the method generalization guarantees diminutive precision in the generated product, which is associated with a low resolution of the base image and only allows a query product with no use for in-depth discussion (Figures 6 and 7).

Figure 6

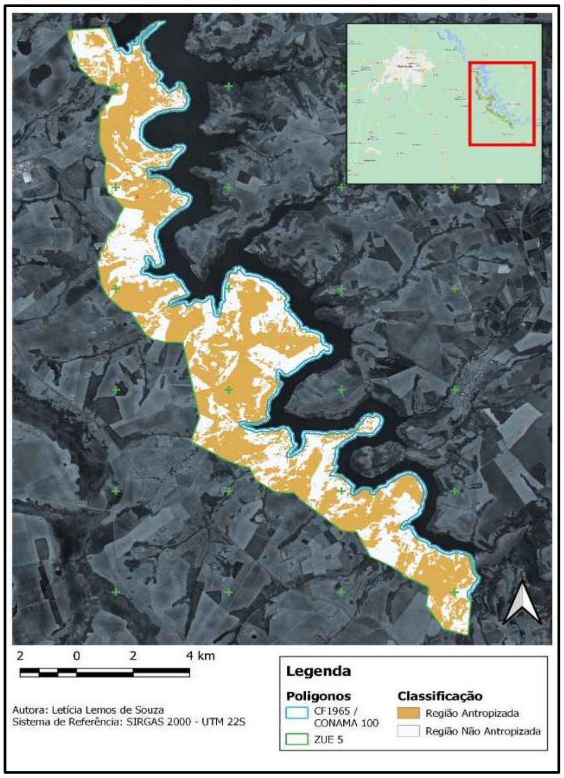
NDBI classification – 2000



Source: Author’s data (2023).

Figure 7

NDBI classification – 2008



Source: Author's data (2023).

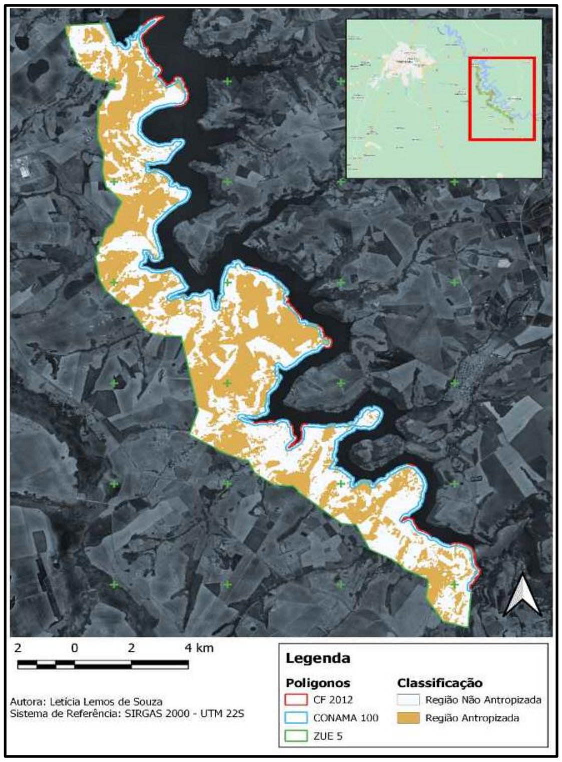
There was a reduction in the non-anthropized area, in relation to the total AOE, from 5.55% in 2000 to 5.34% in 2008, indicating anthropized intervention in values from 3.37% in 2000 to 3.51% in 2008. These values are small, if they consider the proportion of the study area; however, FC (1965)/Conama 100 polygon area is a preservation region that should not suffer from anthropized interventions. This variation *per se* indicates the existence of an activity that should not happen in the region.

With this hypothesis, the NDVI analysis developed for the same area is opposed because there was a reduction in the values of anthropized zone for the region, while there was an increase in indexes of dense vegetation, in the same period. This contradiction can be derived from a potential interpretation of part of the growing vegetation being classified as an anthropized zone in NDBI classification method – despite the density development, it did not prove to be impactful enough to expand the area of non-anthropized zone; and part of the growing vegetation started to be classified as anthropized.

Another important point is the NDBI classification method with some pasture and plantation regions as anthropized zones (Figures 8 and 9):

Figure 8

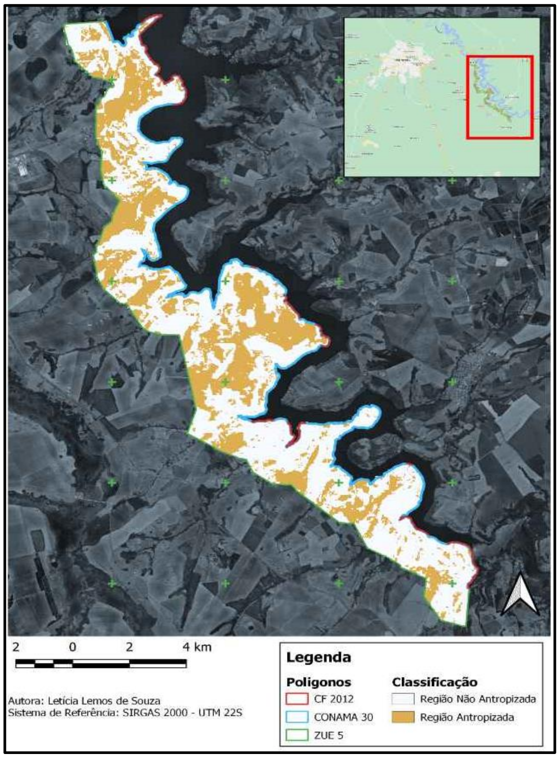
NDBI Classification – 2016



Source: Author's data (2023).

Figure 9

NDBI classification – 2019



Source: Author's data (2023).

The values referring to non-anthropized area varied from 0.20% in 2016 to 0.21% in 2019. This growth does not appear significant, but it is a good indication in relation to the equivalent percentiles of anthropized zone in the region, from 0.011% in 2016 to 0.002% in 2019, i.e., it is close to zero, something indispensable for the environmental quality.

Regarding the area of Conama polygon 30, it maintained the growth trend of non-anthropized zone, from 2.20% of the total in 2016 to 2.39% in 2019. Neither can be interpreted as a significant growth, nor assumed growth greater than 1%; however, it is a satisfactory indication of the quality of the area.

General NDVI and NDBI

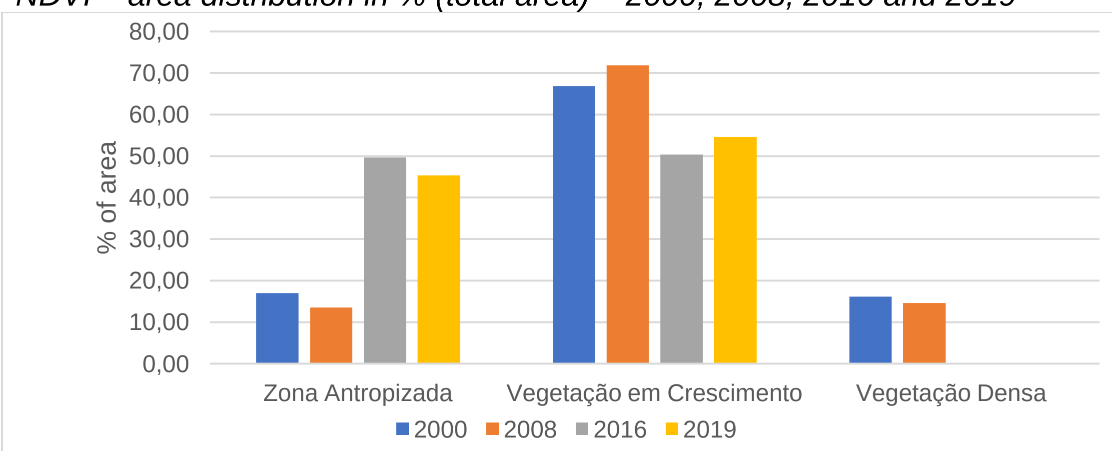
In a comparison about the classifications from 2000, there is a high difference between the values of anthropized and non-anthropized zones. The distinction shows that non-anthropized one corresponds to less than a half of total area in NDBI (equivalent to 47.21%), while the same class makes up 83.03% of the total. These results are directly in accordance with a proposal of the classification method, considering that NDVI disables a more specialized search concerning the cultivation, whose classification limits are better defined, while NDBI classification has a search-oriented focus on construction.

Civil construction is a type of class that encompasses a broad spectral index, as the composition of construction is vast. Thus, in a specific index for classification, as indicated in the methodology, a part of the vegetation cannot be constitutive as an anthropized zone, but it is possible to present such characteristic, especially in regions with drier vegetation, because of the distinct responsiveness.

From this bias, images from 2008 maintained the standard of those from 2000. Even with a relative discrepancy in absolute percentages, which are expected due to the difference in the methods, scales are very nearby: the value of anthropized zone in NDBI classification was 42.86%, while the same class in NDVI presented 86.46%. Undoubtedly, there is still a marked difference in terms of absolute values, but the pattern is a satisfactory indication in this context, as both images were taken from the same satellite.

Figure 10

NDVI – area distribution in % (total area) – 2000, 2008, 2016 and 2019



Source: Author's data (2023).

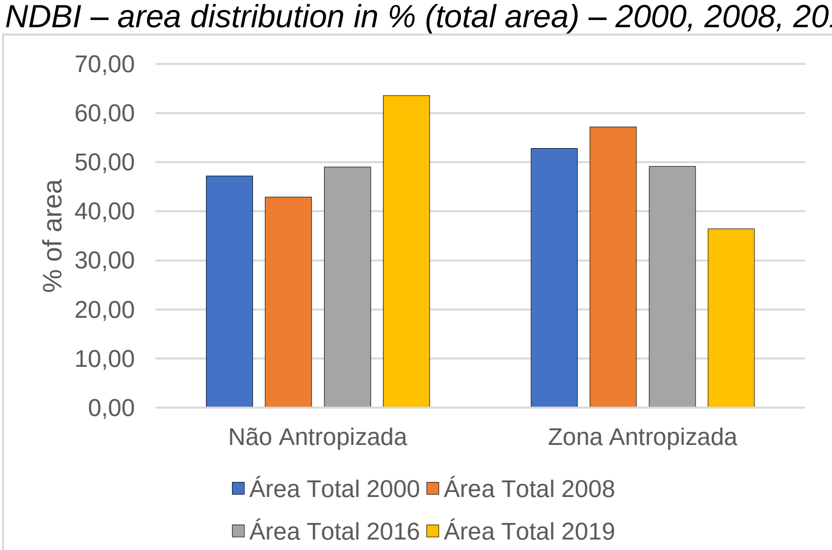
In 2016, classifications percentages were very close: while the anthropized zones in the NDBI were 50.87%, the value of the same class in NDVI corresponded to 50.33%. So, it is a good indication of agreement between the applied classifications because it is slightly significant in contrast to the magnitude of total area, even with a difference in the value. In relation to non-anthropized areas, it is affirmed that they follow the pattern aforesaid.

This relation is justified by the images used for classification that began to be collected with the Sentinel 2 satellite, and no longer with Landsat 5 or 8. With an updated system combined to modern technologies, it enhances the acquisition of images with better quality and less noise interference in the classification result. Differently from 2016, 2019 already presented a greater disparity between the values obtained from the classifications, with 63.56% of non-anthropized area in NDBI and an area of only 54.62% in NDVI classification.

Even with a certain disparity between the values, the distinction is relatively smaller in comparison to data from 2000 and 2008, which refers to a real improvement in the compatibility of methods with the improvement of imaging resources. Thus, there was a similar relation in data behavior concerning each of the applied satellites in the period, leading to a great possibility of identifying the satellite used or, more specifically, the sensors implemented for imaging, such as main impact factor on the classification quality and on the proximity of the relation between NDBI and NDVI classifications.

Figure 11

NDBI – area distribution in % (total area) – 2000, 2008, 2016 and 2019



Source: Author's data (2023).

In 2000 and 2008, the percentage of anthropized zone showed an inverse relation in the analyzed years: while NDVI indicated a greater presence of vegetation, NDBI showed an elevated incidence of anthropized zone. Successively, In 2016 and 2019, the behavior of classifications demonstrated a positive relation: NDVI emphasized the anthropized zone, and NDBI also presented higher values of it, whose standard equally repeated in 2019.

Final considerations

The results showed that areas of vegetative vigor decreased in PPAs and outside them from 2000 to 2016, following the former FC (1965) until the current one (2012) and in accordance with PPA range required by Conama. In some periods, there was an increasing vegetation, but it did not impact the conclusion about the impact caused by urbanization on the banks of Miranda HPP dam. The recovery speed of vegetation after being vandalized spontaneously is lower than the quickness of anthropization.

In one hand, the effectiveness of NDVI index as a tool for environmental, and highly accurate analyzes was noted. The same statement cannot be made in relation to NDBI, which demonstrated data contamination and difficulties in defining the range for areas without vegetation disordered with places of exposed soil, but also with water and asphalt, for example. The inaccurate results from the NDBI application are probably related to free low-resolution satellite images to apply a method that represented insignificant indexes in locations where there is a human interference, whether due to housing or activities undertaken, absence of large vegetation or vegetative vigor and presence of water bodies.

On the other hand, Saraiva et al. (2012), in the study with spectral indices, verified that NDVI and NDBI are used to measure temperatures of land surface that contained vegetation and in consolidated urban areas of Campinas, São Paulo (SP), on three different dates over 15 years. They registered how changes in the pattern of occupation and land use affected the temperature, with a negative relation between NDVI and surface temperature; and a positive one between NDBI and the referred weather. It corroborated the maxim that areas or neighborhoods with a higher rate of vegetation cover have milder temperatures, while the large amount of thermal inertia produces the phenomenon of “heat islands” and, consequently, higher temperatures.

Costa, Augusto e Seabra (2017) conducted a study to analyze the significant urbanization of Rio de Janeiro (RJ) coast, specifically in Lagos Region, using land use and cover mapping produced by one of the research laboratories of State University of Rio de Janeiro (SURJ). NDBI was applied to classify urban areas at random points, in which 83% showed compatibility of the urban use classes with the verified images. The results obtained to measure the efficiency of spectral index were satisfactory and performed well in determining what was urban (or not), even in the face of approximately 8% error due to class conflicts caused by the similarity from spectral response of some surfaces, classification and descriptors used.

Using NDVI and NDBI in Eunápolis, Bahia (BA), Oliveira, Cerqueira Neto and Silva (2021) noted the reduction in vegetation of high vegetative vigor in most part of the municipality. However, in other locations, native vegetation in initial, medium and advanced stages increased from 1996 to 2018, caused by reforestation practices in degraded areas. In order to accurately apply NDBI, it would be necessary to obtain the spectral response of materials such as asphalt, various types of building tiles and water in the laboratory, in addition to acquiring satellite images with better resolution.

The loss or areas depredation with vegetative vigor is an expected consequence arising from the lack of supervision, urban expansion or urbanization of previously legally protected areas. It is not a local reality, as well as a global one; however, the expected population density soon could lead to a loss of environmental balance and high costs for urban management with the creation of urban voids that stimulates real estate speculation and contradicts sustainability objectives.

Rural areas are transformed into urban zones, but continue to have the former characteristics and maybe carry urban design, mobility and infrastructure solutions that will require investments to adapt to future densities. Flauzino (2014) demonstrated that degree of eutrophication found in the reservoirs of Nova Ponte and Miranda HPPs in 2014 is a result of land development for housing or leisure and tourism activities in the region. It has an (in)direct correlation with the water and sediments quality in both reservoirs, because of the influence of land use and occupation; therefore, water resources in that place are very vulnerable to (in)direct human interference.

Otherwise, the creation of SUZ 5 increased the value of land between Miranda dam region (rural and urban) and urban area of Uberlândia (MG), through a large urban void. The form of occupation is a blank page subject to interventions and regulations that achieve ideals of sustainability and print them on its layouts, in which public spaces will be treated and the biodiversity of flora and fauna can be adequately treated.

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