

## Using Brazil Data Cube and Satellite Image Time Series to map Land Use and Land Cover around the reservoir of the Batalha Hydroelectric Power Plant, Goiás (Brazil)

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### Abstract

Accurate Land Use and Land Cover (LULC) maps support the analysis of land use dynamics and provide a scientific basis for land management around water reservoirs. In recent years, technological advancements have led to significant improvements in the methodological design of these mappings. In the context of large-scale Earth Observation (EO) data, satellite image time series (SITS) represent a powerful approach for capturing and measuring surface changes. This study aimed to map LULC in a contributing watershed of the Batalha Hydroelectric Power Plant reservoir, located in eastern Goiás, Brazil. We used the Sentinel-2/MSI time series from Brazil Data Cube (BDC) for the agricultural year (July 2022 to June 2023). The classification included ten classes: Forest Formations, Savanna Formations, Grass Formations, Silviculture, Pasture, Single-Cycle Agricultural Crops, Multi-Cycle Agricultural Crops, Edification, Seasonally Flooded Areas, and Water. We used the Random Forest algorithm and the best practices for assessing mapping accuracy. The results demonstrate the potential of SITS for mapping LULC conditions around water reservoirs. The LULC map generated provides valuable information for managing land use around the reservoir, with a focus on areas where seasonal slope exposure occurs along the immediate reservoir edge. Mapping these areas represents a significant gain in information, as it contributes to the monitoring of sites susceptible to mass movements and marginal erosion processes.

### 1. Introduction

Land Use and Land Cover (LULC) conditions significantly impact soil and water conservation, and their spatiotemporal dynamics can substantially alter the hydrological response of watersheds (Toosi et al., 2025). Changes in land cover act as driving forces behind functional and structural transformations in landscapes and directly interfere with the stability of ecosystem processes, which can lead to their complete degradation (Pompeu, Assis, and Ometto, 2024). Accurate, detailed, and up-to-date LULC maps are crucial for understanding soil protection patterns and identifying land use conditions that may compromise the quality and resilience of terrestrial and aquatic ecosystems (Brijnzeel, 2004; Mashala et al., 2023). Information on LULC is essential for generating strategic knowledge to support the productive sector and guide environmental policy-making in watersheds, especially those near water reservoirs intended for energy production (Silva et al., 2023).

In Brazil, the impacts of LULC changes on watersheds near hydropower reservoirs have been widely emphasized, particularly regarding sediment production, transport, and deposition, as well as nutrient loading, a key driver of eutrophication (Henry, 1999; Carvalho et al., 2006; Tundisi and Tundisi, 2010; Sales, Carvalho and Mascarenhas, 2017; Cabral et al., 2021; Romão et al., 2022; Sales et al., 2024). As complex ecosystems are highly susceptible to water pollution, hydropower reservoirs are significantly influenced by surrounding LULC (Mantei and Foster, 1991; Smith and Schindler, 2009). Under this perspective, LULC dynamics can

either promote soil protection or further exacerbate its disintegration, leading to the transport and deposition of sediments in reservoirs. This negatively affects the energy generation system's efficiency, increases maintenance costs, and reduces the project life (Nunes et al., 2022).

In the Central-West region of Brazil, intensive agricultural practices around water reservoirs, combined with heavy summer rainfall, increase the risks of erosion and the flow of sediment into water bodies, amplifying environmental management challenges in these areas (Oliveira, Wendland and Nearing, 2013; De Souza Dias et al., 2022; Tavares and Castro, 2024). In this context, detailed LULC maps are essential to identify critical areas in terms of soil protection, where the absence of biomass can lead to soil disaggregation and transport into water resources, such as streams, creeks, brooks, and especially reservoirs (Silva et al., 2024). Studies emphasize that agricultural areas without proper soil management and degraded pastures are predominant factors in soil loss, close to the slope and in regions with steep terrain, given the contribution of rainfall erosivity (Robichaud and Brown, 2002; Costa, Nascimento and Da Luz, 2024; Zhao et al., 2024).

Remote Sensing is crucial for LULC mapping (Cihlar and Jensen, 2001). Satellite images are one of the most comprehensive sources of Earth Observation (EO) data. These images directly contribute to measuring the changes that occur on the Earth's surface (Jensen, 2007). Over the past decades, many Digital Image Processing (DIP) techniques and methodologies have been developed, tested, and applied in these mappings (Martins et al., 2023). Due to the advancements

in big EO data availability, cloud computing services, and machine learning algorithms, the analysis of Satellite Image Time Series (SITS) emerges as an innovative and powerful approach for large-scale environmental monitoring and mapping, enabling a more comprehensive and contextualized understanding of land surface dynamics (Miller et al., 2024).

Due to the large volume of satellite imagery, it has been organized as multidimensional data cubes to support time series analysis derived from EO data (Ferreira et al., 2020). SITS data, derived from EO data cubes and integrated with machine learning and deep learning algorithms, represent a significant advancement in LULC mapping (Simoes et al., 2020). The single-date classification approach encounters inherent limitations in discriminating and classifying spectrally similar targets due to the landscapes' complexity and dynamics. Also, in mapping areas of continuous change, such as seasonally flooded areas (Woodcock et al., 2020). The literature shows the potential of SITS to capture events, subtle change patterns, and seasonal trends and generate LULC maps with high accuracy (Picoli et al., 2018; Nyborg, Pelletier and Assent, 2022; Giuliani, 2024; Simoes et al., 2020; Picoli et al., 2020; Simoes et al., 2021; Carlos et al., 2021; Chaves et al., 2021, 2025; Brito et al., 2023; Brito et al., 2025; Souza et al., 2025; Moliniz et al., 2025).

Based on the above aspects presented, it is noted that the surroundings of water reservoirs are areas of significant interest for understanding LULC conditions and soil protection, given their impacts on water resources. Therefore, this study aimed to use the technologies available within the scope of the BDC project, operationalized by the National Institute for Space Research (INPE), to extract SITS and classify LULC in a watershed contributing to the reservoir of the Batalha Hydroelectric Power Plant, operated by Eletrobras Furnas, located in eastern of Goiás, in the division with the state of Minas Gerais, Brazil. Based on the literature, we hypothesize that these technologies enable representative intra-annual mapping of LULC, considering the unique patterns of aboveground biomass growth and decline – soil protection – and the inherent hydrological dynamics of reservoir water levels – the exposure of slopes along their immediate edges. That combines the temporal and spatial information about landscapes in the study area.

## 2. Methodology

### 2.1 Study Area

The study area covers a watershed situated in the municipality of Cristalina, Goiás. This is a significant contributing watershed, comprising five tributaries: Vereda do Salto, Vereda Rapazinho, Samambaia, Paiol, and Rapaz-Grande streams, on the western margin of the Batalha Hydroelectric Power Plant reservoir, covering an area of approximately 485.7 km<sup>2</sup> of the reservoir Direct Influence Area. The construction of the Batalha Hydroelectric Power Plant began in mid-2008. However, it became fully operational only on 17 May 2014 – six years later – after the reservoir, formed by damming the São Marcos River, reached full capacity (Furnas, 2025). It is important to emphasize that this is a region that has undergone an intense deforestation of Cerrado vegetation, followed by the extensive establishment of agro-pastoral activities and, in the last decade has experienced a fast incorporation of intensive agricultural practices (Silva et al., 2021). This region stands out as an important production hub with a high density of center-pivot

irrigation systems, with the greatest concentration in the state of Goiás and in Central-West region of Brazil (Pereira Júnior, Ferreira and Miziara, 2015). The location of the study area is presented in Figure 1.

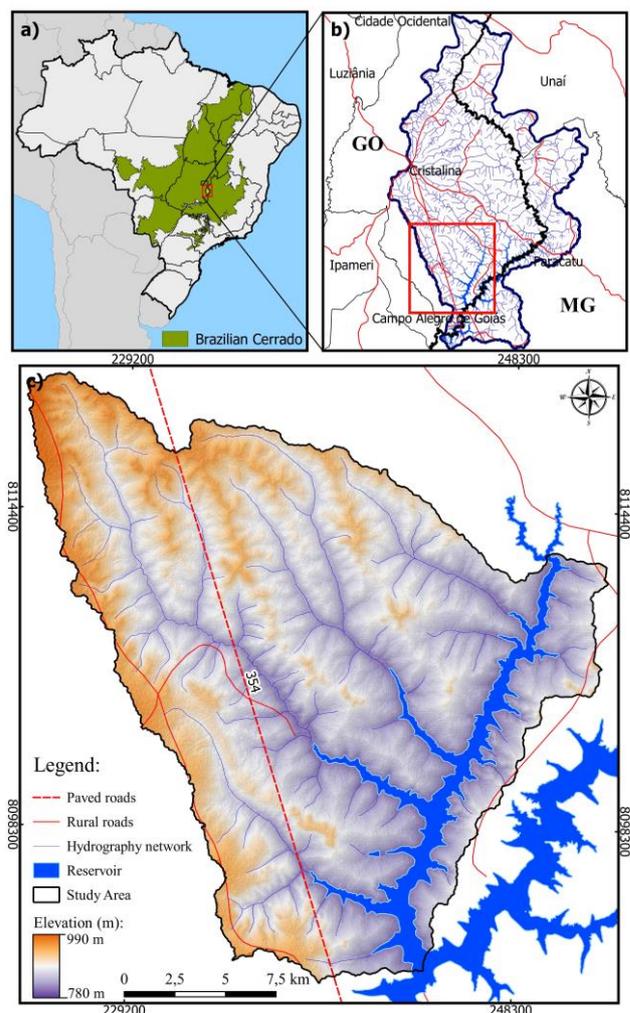


Figure 1. Study area in the Brazil context (a), Batalha reservoir Direct Influence Area (b) and terrain elevation (c).

### 2.2 Input dataset

We generated the LULC map using the data cubes provided by the BDC project. We used a data cube generated from Analysis Ready Data (ARD) of the Multispectral Instrument (MSI) on board the Sentinel-2 satellite, with a spatial resolution of 10 m, projected and clipped on the BDC grid (BDC-Small V2), with a 16-day temporal composition function (SENTINEL-2-16D), considering the Least Cloud Cover First (LCF) best-pixel approach. Specifically, the data cube used in this study covers the regional agricultural year (July 2022 to June 2023), utilizing only the attributes related to the Normalized Difference Vegetation Index (NDVI) proposed by Rouse et al. (1973) and the Enhanced Vegetation Index (EVI), proposed by Liu and Huete (1995). In the literature, these spectral indices have been widely used in LULC mapping to agricultural lands and vegetation cover characterization (Ponzoni and Shimabukuro, 2007; Shimabukuro and Ponzoni, 2012; Santana et al., 2024).

The training dataset initially consists of 1320 samples, which contain the longitude, latitude, start, and end date of the time series (2022-07-12 to 2023-06-26) and a label corresponding to

the thematic mapping class. We used ten thematic classes: Forest Formations (1), Savanna Formations (2), Grass Formations (3), Silviculture (4), Pasture (5), Single-Cycle Agricultural Crops (6), Multi-Cycle Agricultural Crops (7), Edification (8), Seasonally Flooded Areas (9), and Water (10). The land cover classes associated with the Cerrado (Forest Formations, Savanna Formations, and Grass Formations) were defined based on the highest hierarchical level of natural vegetation formations (Level I) proposed by Ribeiro and Walter (2008). Samples for these classes were obtained through visual interpretation of MSI/S2 images, using official data from the TerraClass Project (2022) as a reference. Specifically, we used the thematic class “Primary Natural Vegetation” as a mask in the sample production process for these thematic classes.

Silviculture, Pasture, Single-Cycle Agricultural Crops, Multi-Cycle Agricultural Crops, Edification, Seasonally Flooded Areas and Water classes were included in this study based on previous research conducted at the scale of the Direct Influence Area of the Batalha Hydroelectric Power Plant reservoir (Silva et al., 2023). The reference for these classes was the semi-detailed and detailed mapping of the Direct Contribution Basins and the Limit of the Immediate Margins of the reservoir, respectively, which was also based, in addition to image interpretation, on field data. Specifically, the samples for these classes were collected through visual interpretation of MSI/S2 images and the 2021 reference mapping provided by the aforementioned authors. We emphasize that the thematic class “Seasonally Flooded Areas” does not appear in the previous mapping, although they highlight the seasonal water dynamics in the Limit of the Immediate Margins of the reservoir, in areas mapped by them as “Bare lands”.

### 2.3 Pre-processing

We extracted the time series from the data cube using the `sits` package (Simoes et al., 2021), an open-source R package designed for analysing, visualizing, and classifying satellite image time-series data. Considering that the quality and quantity of samples are critical factors in image classification for LULC mapping (Pelletier et al., 2017; Maxwell et al., 2018), we applied pre-processing techniques to filter out inconsistent and noisy samples/outliers that could compromise the classification integrity. Specifically, the sample dataset was filtered using a neural network-based clustering method, specifically the Self-Organizing Maps (SOM), as proposed by Santos et al. (2021). After using SOM, the dataset retained the samples with the most significant potential to distinguish the chosen labels. Using `sits_kfold_validate`, we performed cross-validation ( $K = 5$ ) and assessed the generalization and robustness of the Random Forest classification model on both the original sample dataset and the cleaned sample dataset. This method reduced variance in data splitting, providing a more reliable estimate of model performance and contributing to a representative classification. This approach is a recommended practice for validating predictive models (Stone, 1974).

### 2.4 Image time series classification

To generate the LULC map, the subsequent step involved training the classifier algorithm. The cleaned sample dataset was used to train the Random Forest algorithm implemented in the `sits` package. The choice of Random Forest was based on the good results recently reported by previous studies in landscapes similar to our study area (Freitas et al., 2025). The distribution

of the clean and balanced sample dataset used is presented in Table 1.

Class label	Count	Prop
Forest Formations	168	0.13
Savanna Formations	153	0.12
Grass Formations	101	0.08
Silviculture	100	0.08
Pasture	136	0.11
Single-Cycle Agricultural Crops	146	0.11
Multi-Cycle Agricultural Crops	137	0.11
Edification	97	0.08
Seasonally Flooded Areas	116	0.09
Water	136	0.11

Table 1. Quantitative and percentage of samples used to train the Random Forest.

After training the model, post-processing methods were applied, as demonstrated by Simões et al. (2021). Specifically, we processed the dataset and obtained the probability map for each thematic mapping class. Next, Bayesian filtering was applied to smooth and refine the map, ensuring a spatially consistent representation. The subsequent steps consisted of class labeling, where each pixel was assigned to the class with the highest probability, and finally, the accuracy measures were assessed following the method proposed by Olofsson et al. (2014). For this final step, we used 2,429 samples collected through the visual interpretation of optical images from Sentinel-2. The open-source software QGIS (version 3.40.7 “Bratislava”) was used for both sample handling and map image generation.

## 3. Results and Discussions

The classification achieved an overall accuracy of 0.90, and a kappa coefficient of 0.89, indicating satisfactory model performance. However, the User Accuracies (UA) for the “Grass Formations” and “Silviculture” classes were low (0.54 and 0.58, respectively), despite the high Producer Accuracies (PA) of 0.90 and 1.00, indicating considerable commission errors. This disparity suggests that while the model fits the training data well (low omission), its predictive generalization is limited in these classes, as evidenced by the commission errors. The “Pasture” and “Seasonally Flooded Areas” classes showed relatively high accuracies, although with room for improvement. Although some classes, such as “Multi-Cycle Agricultural Crops” and “Seasonally Flooded Areas,” showed satisfactory alignment between mapped and error-adjusted areas, the F1 metric reveals that further improvements are very important for others. This is exemplified by the “Forest Formations” class, which exhibited a low F1-score (0.70) resulting from a high UA (0.92) relative to its PA (0.85), indicating a considerable underestimation of its actual spatial extent (Table 2).

Class label	UA	PA	F1
Forest Formations	0.92	0.85	0.70
Savanna Formations	0.94	0.82	0.92
Grass Formations	0.54	0.90	0.66
Silviculture	0.58	1.00	0.74
Pasture	0.82	0.90	0.78
Single-Cycle Agricultural Crops	0.92	0.94	0.94
Multi-Cycle Agricultural Crops	0.99	0.92	0.97
Edification	0.96	1.00	0.98
Seasonally Flooded Areas	0.86	0.84	0.88
Water	0.76	1.00	0.87

Table 2. Classification accuracy measurements.

Based on the LULC map, was identified that approximately 66.5% (32,285 ha) of the study area is dedicated to agricultural and livestock activities – Figure 2. Croplands dominate these land uses, covering 27591 ha (57% of the total area), followed by extensive pastures, which account for 4460 ha (9.18%). Silviculture and Edification areas (including houses, storage bins, and other infrastructure) represent only 0.5%. The areas mapped as “Water” (1363 ha, 2.81%) represent lotic ecosystems in the study area, especially the reservoir of the Batalha Hydroelectric Power Plant and other small impoundments, which predominantly occur along tributary channels. In this context, the class “Seasonally Flooded Areas” (933 ha, 1.92%) represents adjacent zones subject to periodic flooding in response to the inherent seasonal hydrological fluctuations of these ecosystems (Tundisi, 2010).

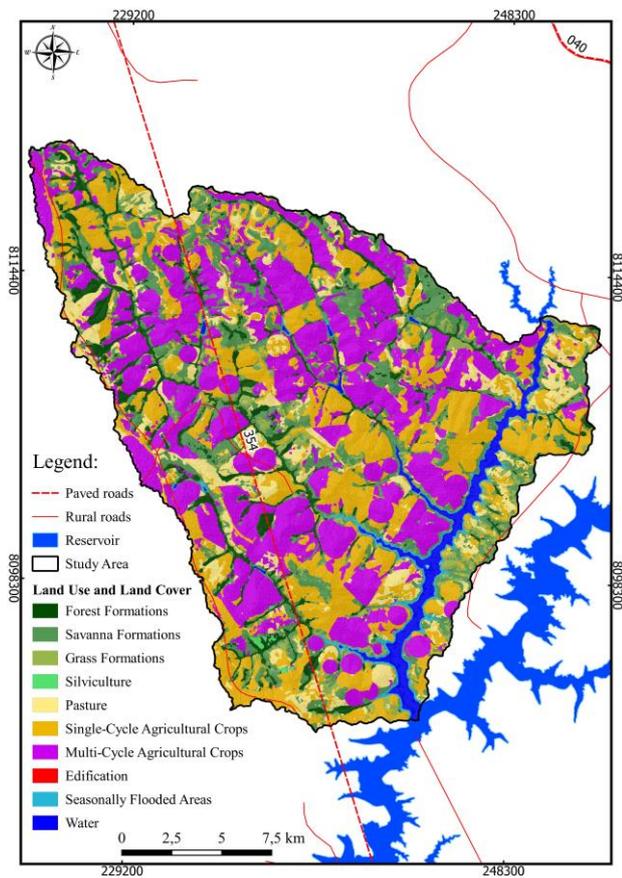


Figure 2. LULC map of the study area.

According to Sales et al. (2024), reservoir water level fluctuations can compromise structural soil stability along the reservoir margins (depletion areas), and this dynamic can trigger and/or intensifying bank erosion processes (De Souza Dias et al., 2022). In this context, we highlight how the mapping of “Seasonally Flooded Areas”, demonstrated here using time series analysis, provides significant informational gains, contributing for erosion management. For example, mapping these areas can support the implementation of conservation strategies in Permanent Preservation Areas (PPAs) surrounding the reservoir; identification of upstream deposition areas upstream of the dam; prioritization of sites or stretches for landslide containment interventions, and more. This aims to protect environmental integrity, to ensure water quality, biodiversity, and geosystemic stability on the immediate edges of the reservoir, areas usually affected by marginal erosion.

In contrast to anthropogenic land use, the natural vegetation cover of the Cerrado account nearly 29% (13,988 ha) of the study area. Savanna Formations (7,355 ha; 15.14%) represent significant remnants of native vegetation, prevailing at the landscape scale, followed by Grass Formations (3,423 ha; 7.05%) and Forest Formations (3,211 ha; 6.61%). Silva et al. (2021) observe that the current landscape surrounding the Batalha Hydroelectric Power Plant reservoir reflects the historical expansion of the agricultural frontier in the region. According to the authors, since the 1980s, the continuous natural vegetation landscapes of the Cerrado in this area had already been converted into extensive pasturelands with the introduction of exotic species, mostly the African *Brachiaria* (Boddey et al., 2020). However, in recent years, a significant part of these areas has been replaced by intensive agricultural systems, such soybean and corn cultivation.

In the Figure 3 are presented field photos of the remnants of native Cerrado vegetation in the three predominant types (Savanna Formations, Grass Formations, and Forest Formations). According to Ribeiro and Walter (2008), Savanna Formations are characterized by landscapes with varying densities of tree-shrub species, associated with an herbaceous layer dominated by grasses. Grass Formations, in turn, consist of predominantly herbaceous-shrub environments with sparse occurrences of small trees. Dense clusters of medium to large-sized trees, with distinct floristic composition and high density, on the other hand, define Forest Formations. These Cerrado remnants, although fragmented, are an essential component for maintaining diverse ecosystem services, particularly hydrological ecosystem services, in the reservoir surrounding. In addition to promoting the infiltration and recharge of groundwater, it reduces surface runoff from agricultural land, containing the transport of sediment (Sales et al., 2024).



Figure 3. Field photos of the Cerrado remnants (a-Savanna Formations, b-Grass Formations, and c-Forest Formations).

In the Figure 4 are presented field photos of the different forms of land use. Figure 4a contrasts silvicultural lands, including

harvested zones, with extensive croplands and pasturelands. Figure 4b depicts croplands at different growth stages of irrigated soybean under center-pivot systems, representing areas of technical intensification. Figure 4c illustrate corn croplands and agricultural fields where crops have already been harvested, with soil in a fallow stage being prepared for replanting. The partial or complete soil exposure during field preparation represents a typical intermittent event in the agricultural calendar (between harvests), where aboveground biomass may become virtually absent. This temporary condition, while common in agricultural cycles, can significantly increase soil susceptibility to water erosion, especially at the beginning of wet season, due to torrential rainfall events in the region (Costa, Nascimento and Da Luz, 2024).

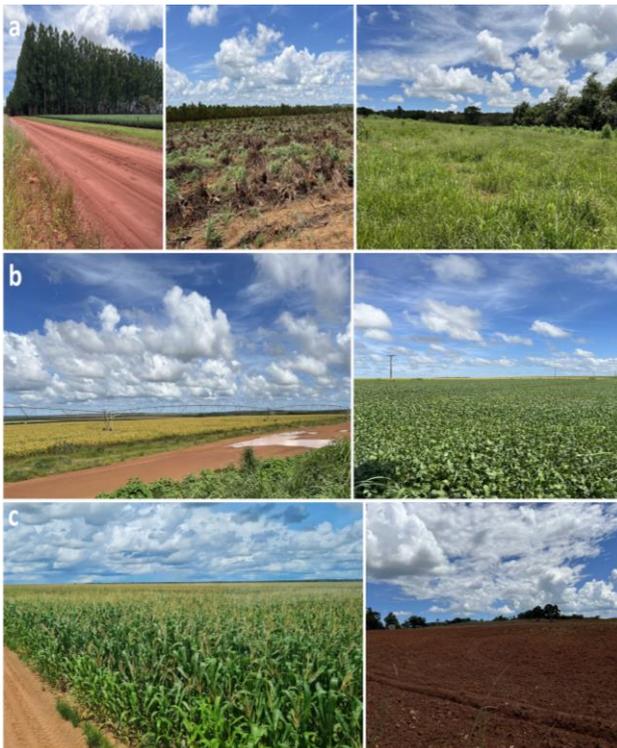


Figure 4. Field photos of the different forms of land use.

According to Verburg et al. (2015), the intersection of human activities development and ecosystems conservation presents critical challenges, particularly regarding changes in LULC and the protection of water resources. Around water reservoirs, this unique demand leads to the need to balance different forms of land use with conservation practises, especially because these ecosystems are slow-flowing, making them slightly sensitive to fast changes in their biotic and abiotic variables. LULC changes are one of the main drivers of land degradation through erosive processes and significantly contribute to variations in surface runoff, which can trigger deep transformation in ecosystem structures and functions across multiple scales and intensities (Dedecek, 1988; Sales et al., 2024). In this context, a consistent and detailed LULC mapping can help understand resource use dynamics and thus provide a scientific basis for land management around water reservoirs.

The historical transformation of natural landscapes into human-made environments, particularly with the prevalence of cropland surrounding the reservoir, highlights the critical need to preserve fragments of the natural Cerrado vegetation. Moreover, it emphasizes the necessity of implementing effective

land-use planning practices (Zolin et al., 2021). These efforts play a vital role in mitigating erosion and limiting the influx of sediments and nutrients into adjacent waterways and the reservoir, thus helping to prevent siltation and eutrophication (Bihonegn and Awoke, 2023). Although eutrophication and sedimentation are natural phenomena over long timescales, human activities can intensify them. The excessive enrichment of water resources with nutrients is linked to the over proliferation of organisms such as algae and cyanobacteria, which are becoming increasingly common in lentic ecosystems (Nogueira et al., 2015; Dondajewska et al., 2019; Česonienė et al., 2023). Therefore, understand land-use is so important for effective water resource management and conservation.

#### 4. Final remarks

The use of the Brazil Data Cube and satellite image time series enables the consistent mapping of LULC around water reservoirs. The intensification of land use around water reservoirs, especially those for energy production, means that the productive sector and public policy makers to rely on increasingly consistent, detailed, and up-to-date information, which is essential for understanding and analysing trends in resource use, thus supporting decision-making.

The results also demonstrated that the use of time series allows for better identification of dynamic areas, such as those where seasonal exposure of slopes occurs along the immediate reservoir edge. Mapping these areas represents a significant gain in information, as it contributes to monitoring locations susceptible to mass movements and marginal erosion processes. Despite an overall accuracy of 0.90, the uncertainties associated with the class remain an aspect to be improved.

The pronounced commission errors in specific classes, such as Grass Formations ( $F1=0.66$ ) and Silviculture ( $F1=0.74$ ), coupled with omission errors in Forest Formations ( $F1=0.70$ ), highlight a critical challenge in disambiguating spectrally analogous natural vegetation. We suggest that future efforts prioritize refining temporal features in these areas, opportunely, integrating more field-collected data. We also emphasize that sits package provides support for improve classifications through an iterative process of sample selection, labeling, and model retraining (Active Learning).

For future research endeavors, it is recommended to explore other machine learning and deep learning methods, as well as other multispectral attributes, including Sentinel-1 images. In the context of mapping natural vegetation cover of the Cerrado biome at more detailed scales, specifically the Level II and III classifications as proposed by Ribeiro and Walter (2008), this presents an important topic for further investigation and remains an open research topic.

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