ESTIMATING CHLOROPHYLL-A CONCENTRATION IN JOÃO LEITE RESERVOIR USING HIGH SPATIAL RESOLUTION REMOTE SENSING DATA

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Abstract

The excessive emergence of organisms such as algae and cyanobacteria is increasingly common to be observed in water reservoirs. This process results mainly from the enrichment of water bodies by nutrients, from areas with agricultural activities and/or the discharge of domestic and industrial sewage. Although eutrophication is considered a natural process over long time scales, human activities can directly enhance it. This paper estimates the concentration of Chlorophyll-a in the João Leite reservoir, located in the Metropolitan Region of Goiânia, state of Goiás, Brazil. For this, it is based on processing satellite images with high spatial resolution, using a space-first approach, July 6th, 2023. The results show that the most part of the reservoir presented values between 20.0 mg/m³ and 80.0 mg/m³, highest estimated values (above 85.0 to 128.0 mg/m³) are concentrated near the dam. Chlorophyll-a occurrence and concentration may be related to intensive land use around the reservoir.

Key words: Water Quality, Sattelite Image, Digital Image Processing, Google Earth Engine.

1. Introduction

The construction of reservoirs is central to the storage and distribution of water to multiple uses by population, especially in large cities, given that as cities grow in population, the total water needed for adequate municipal supply grows as well (FALKENMARK and WIDSTRAND, 1992; BRADLEY et al., 2002). By storing still or slow-flowing water, in addition to their multiple uses (i.e., power generation, irrigation, animal watering), reservoirs also provide essential ecosystem services, such as: cycling pollutants and nutrients, making them one of the key components of biogeochemical processes; and regulating the climate through the carbon cycle (WILLIAMSON et al., 2009). Being, in essence, complex functioning ecosystems, the reservoirs are subject to rapid changes in their biotic and abiotic variables. This is due to the natural variability of the environment, but which can be accelerated or altered due to the dynamics of land use and land cover dynamic and water resource demands to multiple use (TUNDISI, 1999).

It is worth mentioning that this intervention in the environment, resulting from the transformation of lotic environments into lentic ones, becomes a vector for a series of impacts on ecosystems, such as changes in the natural cycle, composition and water quality in drainages upstream and downstream of the dam (OLIVEIRA, 2009; PICAPEDRA et al., 2020). These changes may also reflect the dynamics of land use and land cover intrinsic to the implementation and operation of a hydroelectric project (SILVA et al., 2023). Diffuse and localized pollution, coming mainly from agricultural land and domestic sewage, contributes a great input of micro and macronutrients, leading to alteration of the water body's trophic state. Over time, high nutrient input harms water quality, leading to an expressive increase in primary production, frequency of cyanobacteria blooms, and fish mortality. In the context of global climate change, this means that eutrophication can cause a rapid decrease in phytoplankton biodiversity and then lead to the reservoir, gradually, losing its multiple uses and becoming a severe threat to public health (RIGOSI et al., 2014).

Several factors trigger changes in the physical, chemical and biological characteristics of aquatic ecosystems. Firstly, due to the intensive use of the soil by agricultural activities around the reservoir, with the use of fertilizers and pesticides. There is also the fragmentation and gradual destruction of the vegetation that accompanies the watercourses (riparian and gallery forests), which attenuate the conditions for water infiltration into the soil and intensify surface runoff. It is also important to highlight the discharge of domestic and industrial sewage without adequate treatment (DOWNING et al., 1999). It is relevant cite that, over the last century and more strongly last decade, fast urbanization has seriously affected the water quality of near-cities reservoirs in different parts of the world (CAIRO et al., 2020). Therefore, for better governance of inland water resources, it is necessary to improve the monitoring of water quality in reservoirs.

In this paper, Sentinel-2 MSI (Level 2A) orthorectified and atmospherically corrected surface reflectance images were used with the purpose of estimating the concentration of chlorophyll-a (chl-a), the main indicator of the trophic state of aquatic environments. The study area comprises the João Leite reservoir, located in the Metropolitan Region of Goiânia, state of Goiás, Brazil. By definition, chlorophyll is the photosynthetic pigment present in all phytoplankton organisms. Chlorophyll-a (chl-a) is the most common of the chlorophylls (a, b, c and d) and represents approximately 1 to 2 % of the dry weight of organic matter in all algal species. For this reason, knowledge of its concentration is used to detect the proliferation of algae and understand its dynamics in aquatic ecosystems like multi-purpose artificial reservoirs and lakes. Thus, the concentration of chl-a is the main indicator of the trophic state of aquatic ecosystems, especially lentic ecosystems (TOLEDO JÚNIOR, 1983; KUTSER, 2004; LOPES, et al., 2015).

3. Methodology

3.1 Theoretical and methodological approach

This study is presented as an exploratory and descriptive study. The methodology consisted of a literature review, which sought the state of the art and renowned authors in relation to the topic, and Digital Image Processing (DIP) from Orbital Remote Sensing. Specifically, the DIP was based on optical orthorectified atmospherically corrected surface reflectance imagens, derived from the MSI (Multispectral Instrument) sensor system, aboard the Sentinel-2 satellite (Level-2A). The justification for which the decision was made to use these data, is due to the fact that, in addition to these data being available free to the community, which in itself makes them widely used in a diversity of studies, these data (images) also have a spatial resolution of 10 m, which characterizes them as high spatial resolution images (EHLERS et al., 2002), making it possible to use them on a scale of 1:25,000, it means, semi-detail mappings.

The access to data and its processing routines occurred in the Google Earth Engine environment, with programming in Java Script language. One of the advantages of this processing environment is that, in addition to the possibility of working with big Earth observation data collections, it has extensive computing capacity for processing geospatial data in the cloud (Cloud Services), where users have at their disposal, until now, free access to a robust collection of Machine Learning and Deep Learning algorithms (GORELICK et al., 2017). The data used in this study are from the Sentinel-2 satellite (Analysis Ready Data), made available within the scope of the Copernicus Earth Observation Program, on European Space Agency (ESA).

Considering a time window of 31 (thirty-one) days, which comprises the month of July of the year 2023, justifiably because it is the month that historically presented the lowest cloud coverage in the context of the study area, the dataset was filtered, and 9 (nine) images were found with cloud coverage ≤ 10% (less than or equal to nine percent). Paying attention to these data with cloud coverage ≤ 10%, and the premise that in Optical Remote Sensing the occurrence of clouds can cause errors in the interpretation of reflectance data, where these errors can be transferred to the proposed equations and on the results (BARRAZA-MORAGA et al., 2022), specifically, the image that best met the processing conditions and was defined to be processed in this study, its date is July 6th, 2023, its percentage of cloud coverage is 0.02%.

As already mentioned, there is a diversity of theoretical-methodological approaches in the literature regarding the estimation of inland water quality using DIP from orbital sensor systems (NOVO, 2007; RUDORFF et al., 2007; GONÇALVES et al. 2017; VAIBHAV et al., 2020; OGASHAWARA et al., 2021; BARRAZA-MORAGA et al., 2022; SANTOS et al., 2023). With regard to the concentration of chlorophyll-a, specifically, it is possible to find methodologies anchored from bio-optical models, which take into account remote sensing measurements, such as Spectral Indices, to more robust algorithms, for example, Deep

Learning. It is important to highlight that the different theoretical-methodological approaches regarding the estimation of inland water quality are not necessarily mutually exclusive, but above all, complementary.

To estimate the concentration of chlorophyll-a, this study uses as a reference the bio-optical model that takes into account the Normalized Difference Chlorophyll Index – NDCI (MISHRA and MISHRA, 2012), according to Equation 2, and the M12A calibration empirical algorithm, whose coefficients are described in Equation 3, developed for data from different orbital sensor systems and which has been widely used in multispectral bands of the MSI sensor system on board the Sentinel-2 satellite, Level-2A (DALL'OLMO and GITELSON, 2005; GONS et al., 2008; AUGUSTO-SILVA et al., 2014; MARCÉ et al., 2016). Bio-optical models are parameterized to adjust to the width of the multispectral bands of the sensor systems coupled to satellites, so that they can be used to estimate biogeochemical concentration in large areas. This model (NDCI/M12A) was chosen mainly because the NDCI is relatively simple to implement and subsequently used in the M12A calibration, (Equation 3). In addition, the Normalized Difference Water Index - NDWI (MCFEETERS, 1996) was used to identify and map only the water bodies (Equation 1), the object of study.

Equation (1)

$$NDWI = \left(\frac{pGreen - pNIR}{pGreen + pNIR}\right)$$

Where:
pGreen = Surface Reflectance in *Green* band;
pNIR = Surface Reflectance in *NIR* band;

Equation (2)

$$NDCI = \left(\frac{pRed\ Edge\ 1 - pRed}{pRed\ Edge\ 1 + pRed}\right)$$

Where:
pRed Edge 1 = Surface Reflectance in *Red Edge 1* band;
pRed = Surface Reflectance in *Red* band;

Equation (3)

$$Chlorophyll - a(mg/m^3) = 194.325(NDCI)^2 + 85.115(NDCI) + 14.039$$

The dynamics of land cover and land use around reservoirs can be associated with the quality of their waters, and reflect the eutrophication of lotic and lentic water bodies. In order to better understand and describe the conditions of land use and land cover in the context of study area, statistics from MapBiomas (MAPBIOMAS, 2023), edition 7, were accessed and used at the scale of the municipalities (Goiânia, Goianápolis, Nerópolis and Terezópolis de Goiás) where the João Leite reservoir is partially located. The land cover and land use data made available within the scope of MapBiomas results from the digital images classification from the Thematic Mapper (TM), Enhanced Thematic Mapper Plus (ETM+) and Operational Land Imager (OLI) sensor systems, on board the Landsat 5 satellites, 7 and 8, respectively, with a spatial resolution property of 30 m.

3.2 Study Area

The study area comprises the João Leite reservoir, located in the Metropolitan Region of Goiânia, in context of the central part of the state of Goiás, Brazil. The watershed where the João Leite reservoir is located includes the municipalities: Anápolis, Campo Limpo, Goianápolis, Goiânia, Nerópolis, Ouro Verde de Goiás and Terezópolis de Goiás. Although the total area of the watershed is approximately 76,200 hectares, it is important emphasize that the area occupied by the reservoir cover, partially, only the municipalities of Goiânia, Goianápolis, Nerópolis and Terezópolis de Goiás (Figure 1). One of the most important reasons for setting up the João Leite reservoir on 2005 was the need for a source that could guarantee water supply for the population of the Metropolitan Region of Goiânia (RMG), which currently has more than 2.173.006 inhabitants and shows a strong tendency to grow in the next years (IBGE, 2022).

According to information available on the Companhia Saneamento de Goiás S/A, main responsible for sanitation in most of the municipalities in the state of Goiás (SANEAGO, 2023), Goiânia, the main city in the RMG, have three water-producing systems, which have two water sources: the Meia Ponte, surface catchment system, and the João Leite, witch a dammed water catchment system. The Meia Ponte system is made up of the direct catchment of the Meia Ponte river and the Water Treatment Plant (WTP) of river Meia Ponte; while the João Leite system covers, directly, the respective reservoir with the same name (João Leite), and the WTP Mauro Borges and the WTP Jaime Câmara. The strong urbanization process associated with the consequent population growth generates a high demand for water sources for multiple uses in large cities and their inter-urban areas (LINO, 2013; NASCIMENTO and OLIVEIRA, 2015). Considering the population of the RMG (IBGE, 2022), in relation to 2010, Abadia de Goiás, Goianira and Senador Canedo comprise the three municipalities of the REM with the highest population growth: 178.18%, 111.15% and 84.31%, respectively. In the same period, Goiânia had a population growth of 10.4%.

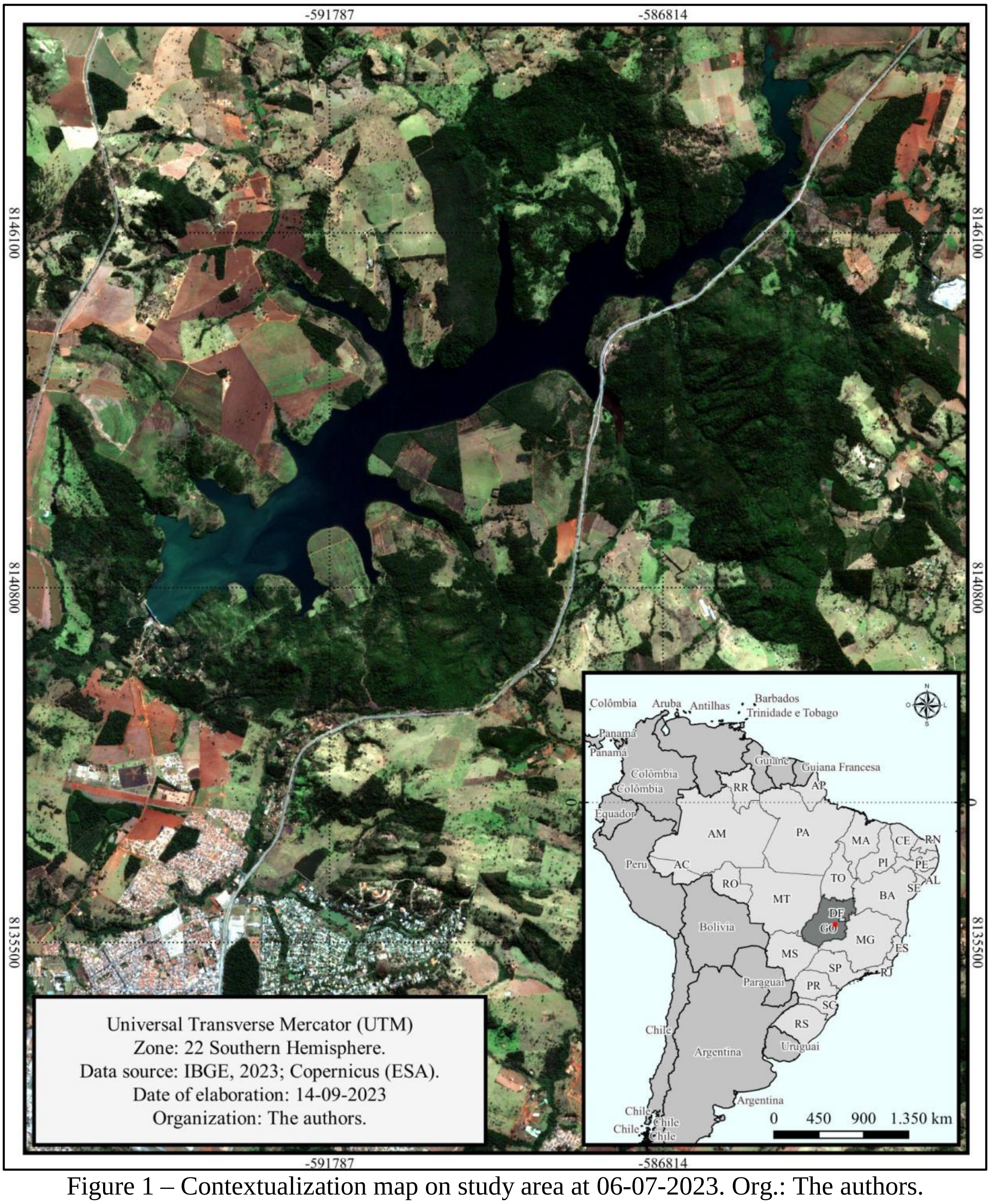

Figure 1 – Contextualization map on study area at 06-07-2023. Org.: The authors.

4. Results

Figure 2 shows the estimated concentration of Chlorophyll-a (mg/m³) in the João Leite reservoir on July 6th, 2023. The estimated values range from 20.0 to 128.0 mg/m³. Spatially, the most part of the reservoir shows values between 20.0 mg/m³ and 80.0 mg/m³. The highest estimated values (above 85.0 mg/m³) are concentrated near the dam (Figure 2). This is associated with the fact that this is the widest part of the reservoir, and consequently the part where the water flow tends to be significantly lower than that observed upstream, thus favoring this concentration, a spatial pattern observed in lentic ecosystems.

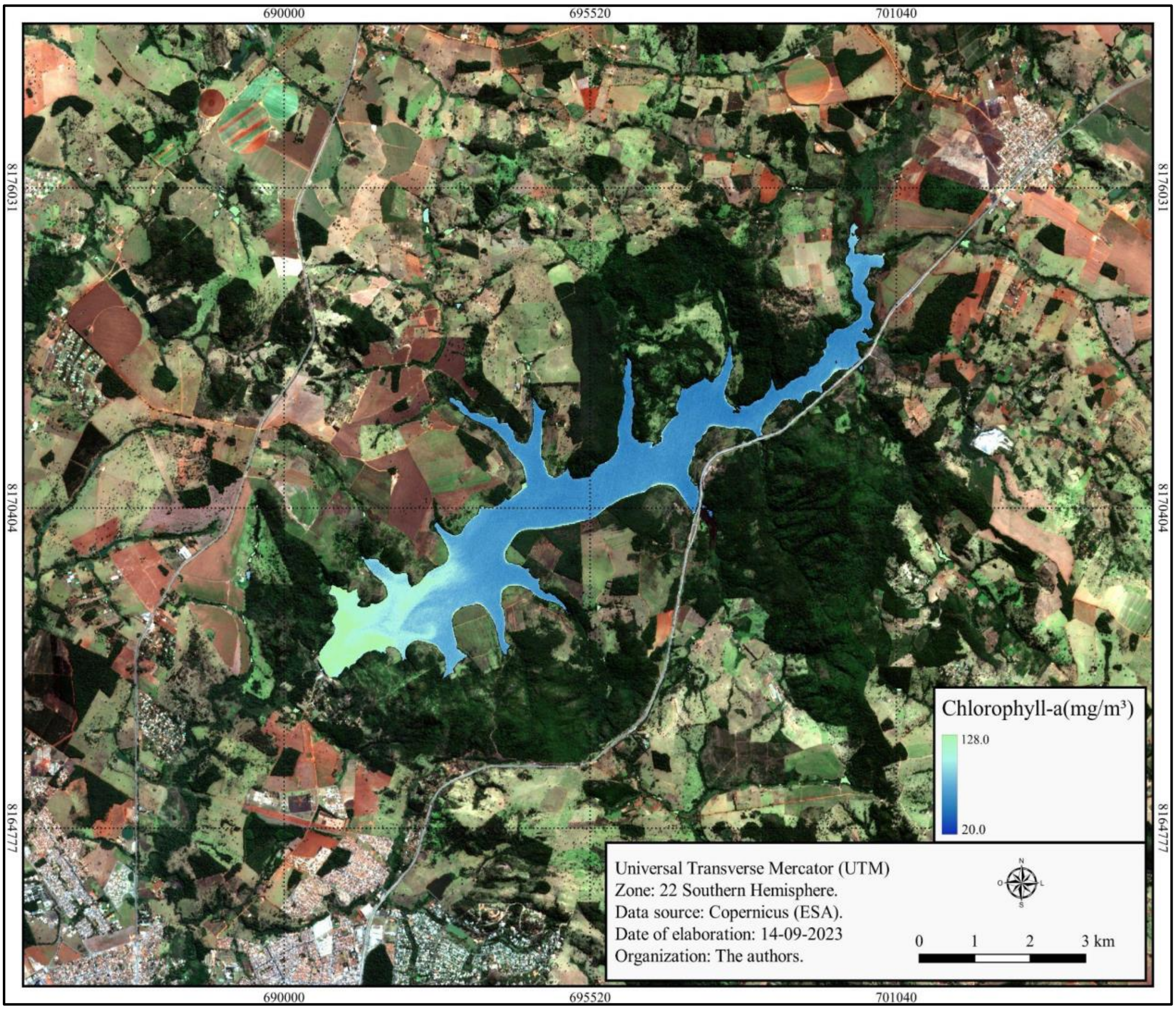

Figure 2 – Chlorophyll-a (mg/m³) concentration in João Leite reservoir at 06-07-2023.
Org.: The authors.

To the context of land use and land cover on the surrounding area, it is possible to note the presence of vast areas of bare soil, areas which are used for agricultural activities, but which are left fallow at this time of year (SOUZA, 2013). It is known that the conditions of land use and land cover can provide protection or accentuate the disintegration, transportation and deposition of soil and other associated materials inside them, where areas of use related to agricultural activities can become one of the critical factors in relation to the quality of the reservoir's water and the effectiveness of its useful life (SALES et al., 2017; SOUZA DIAS et al., 2022; SILVA et al., 2023), bearing in mind that, if not properly managed, these activities can directly contribute to the enrichment of the water with nutrients (especially nitrogen and phosphorus in their different forms) and, in the short, medium and long term, lead to an increase in the biomass of cyanobacteria and a drastic reduction in submerged macrophytes, resulting in their eutrophication (DONDAJEWSKA et al., 2019).

More recently, Oliveira (2023) conducted a detailed study of the temporal analysis of the dynamics of land use and land cover in the watershed of João Leite reservoir and highlights that fragmentation and gradual destruction of the vegetation that accompanies the watercourses (riparian and gallery forests) it is a critical problem, mainly because they are Areas of Permanent Preservation (APP) with many conflicts of use. According to the author, by 1985, human activities in the João Leite watershed were highly significant, covering around 77.3% of its length. This was reflected in the presence of extensive areas of pasture that dominated the landscape in a remarkably homogeneous way in the region. Agricultural activity, with special emphasis on soybean and corn cultivation, was predominantly concentrated in low-elevation areas, notably in the municipality of Goiânia, Goiás. The presence of mosaics of agriculture and grazing was evident in large blocks throughout the João Leite watershed, as well as in sizable patches in the upstream landscapes.

Analyzing the dynamics of land use and land cover conditions in 2021, specifically, Oliveira (2023) highlights that, 36 years after the first year of observation (1985), and 12 years after the reservoir was filled, land use conditions in the watershed have maintained a direct relationship with livestock-related activities, although a 7.26% reduction in pastureland use areas was observed between 1981 and 2021, and in this last year (2021) pastureland use areas still represented around 36.46% of the total watershed area; unlike the agricultural activities, which showed an increase of approximately 6.25% in the areas of use, what indicate the change of land used for pasture on land used focused on agriculture, a pattern observed in various regions of the brazilian Cerrado.

Associated with these processes inherent to land use in the watershed, it was possible to observe a slight increase (2.70%) in the urbanized area between 1985 and 2021. Potentially, this related to the growth of the urban sprawl of cities such as Goiânia, Anápolis and Senador Canedo; and a slight increase (1.6%) related to the areas identified and mapped as water bodies, possibly showing the filling of the João Leite reservoir and the creation of other small reservoir

for animal desedentation and pisciculture. In Figure 3, land use and land cover scenarios (1985, 2005, 2021) are presented on the scale of municipalities where the Joao Leite reservoir is located (Goiânia, Goianápolis, Nerópolis and Terezópolis de Goiás).

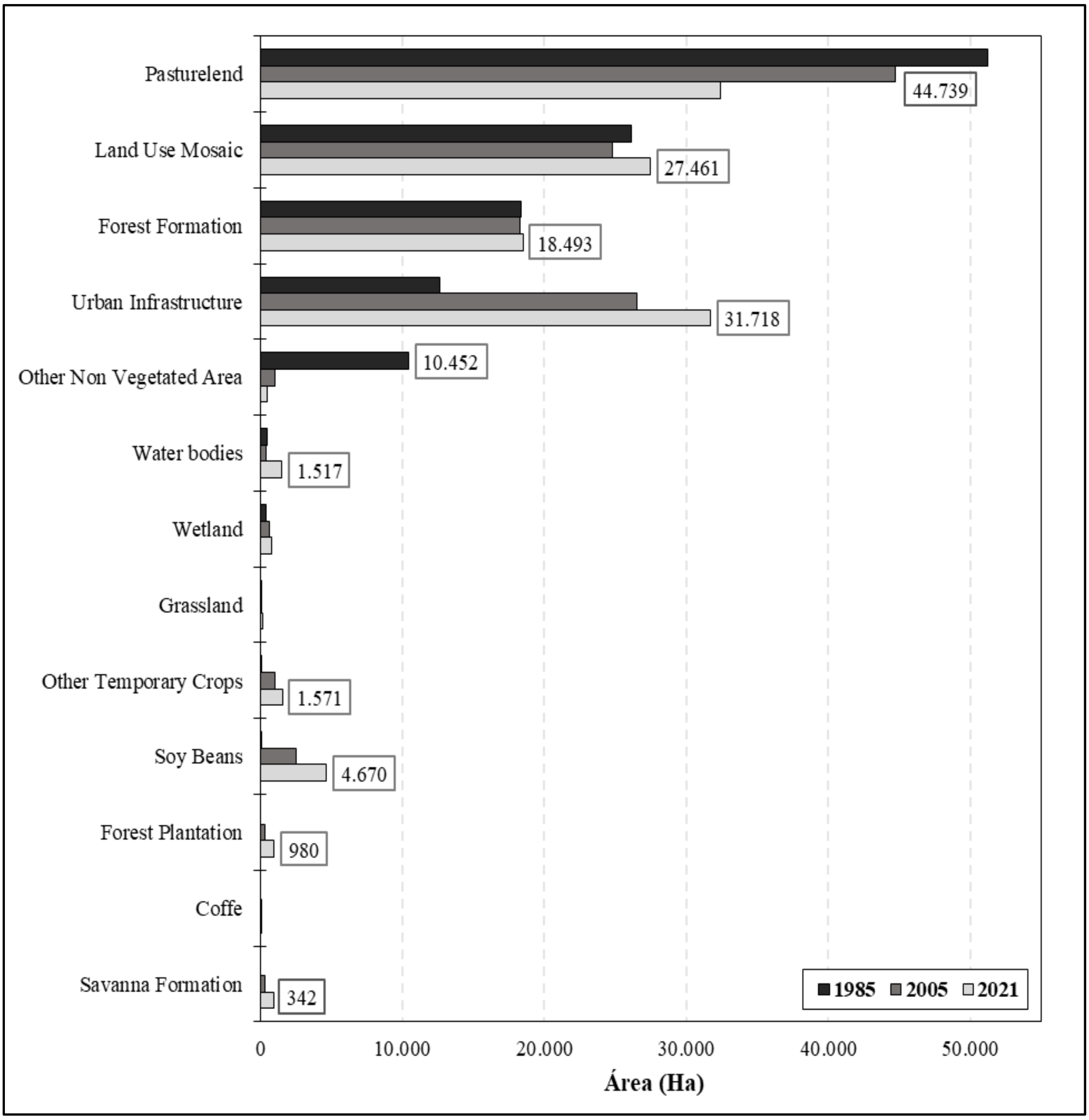

Figure 3 – Land use and land cover scenarios in the context of municipalities where the João Leite reservoir is located. Org.: The authors.

Given these scenarios (1985, 2005 e 2021), it can be seen that there were few dynamics in relation to the areas covered by natural vegetation. It is possible to observe a subtle increase in the areas covered by Forest Formations and Savannah Formations, possibly due to the Forestal Code, in the context of intensified inspection and penalization of practices of suppression of natural vegetation cover (BRASIL, 2012).

5. Conclusions

The input of nutrients is a major problem related to artificial reservoirs,which can lead to eutrophication. Using the methodology employed in this study, it was possible to achieve the objective of estimating the concentration of chlorophyll-a in the João Leite reservoir. The knowledge of chlorophyll-a concentration is so important to detect the proliferation of algae and understand its dynamics in aquatic ecosystems with multi-purpose. In this sense, for future studies, the authors suggested using BDC (Brazil Data Cube) and SITS (Satellite Image Time Series) to extract time series of estimated chlorophyll-a concentration in João Leite reservoir. The Time-First approach will allow creating chlorophyll-a concentration time series to assess the impact of land use on the increase of algae blooms in reservoir João Leite. Similarly, the authors emphasize that: it is necessary to validate the results with in situ data in order to verify the accuracy of the mapping for the reservoir.

Understanding the conditions of land cover and land use around the João Leite reservoir is extremely important in order to advance our understanding of the occurrence and concentration of chlorophyll-a in the reservoir. Although there are several published studies dealing with land cover and land use in the watershed, attention should be drawn to the fact that very few studies have worked with more detailed data and scale, emphasizing, for example, the marked seasonality in areas used for agricultural activities. According to Martini et al.,(2006), in lentic water systems, primary productivity has a strong relationship with the input of nutrients from terrestrial ecosystems, which reinforces the need to consider the intra-annual dynamics of land use in the occurrence and concentration of chlorophyll-a in reservoirs.

Downstream of the reservoir, higher concentrations of chlorophyll-a were observed. As mentioned above, this pattern may be associated with the fact that this is the widest part of the reservoir, and consequently the part where the water flow tends to be significantly lower than that observed upstream, thus favoring this concentration, a spatial pattern observed in lentic ecosystems; as well as to the intensive land uses that occur in the vicinity of the first-order channels closest to the immediate edge of the reservoir, which can carry, directly, flows of materials from these areas, not only by surface runoff, but also by wind. Furthermore, this demonstrates the importance of field activities.

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