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SPATIOTEMPORAL ANALYSIS OF LAND USE AND LAND COVER USING REMOTE SENSING

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KEYWORDS

Landsat5, RapidEye, PlanetScope, GIS.

ABSTRACT

Land use and land cover (LULC) changes, essential to understanding environmental dynamics under human influence, are significantly intensified by the agricultural sector. This study aims to characterize and analyze spatiotemporal changes in an area primarily influenced by agricultural activities, using geoprocessing and remote sensing. The methodology involved acquiring satellite images from the wet and dry seasons of 1990, 2000, 2010, 2020, and 2023, then delineating and analyzing LULC classes. Among the analyzed periods, the most significant change was the shift from temporary crops to exposed soil, attributed to the fallow period. In contrast, forest areas, buildings, pastures, lagoons, transmission lines, motorways, and access roads underwent only minor alterations. Since 1990, pastures, forest cover, and temporary crops have been the most prevalent classes, totaling 735, 686, and 533 hectares, respectively, during the 2023 rainy season. In conclusion, the methods used here can be adapted to any region, and the resulting products provide essential tools for managers to devise strategies that enhance agricultural and environmental management.

INTRODUCTION

Land Use and Land Cover (LULC) are key factors in understanding how human activities interact with the environment. Monitoring LULC is crucial for assessing changes that may harm ecosystem services or aid their restoration (Caten et al., 2015; Fikadu & Olika, 2023). Although LULC changes have occurred over long periods, their effects have become more pronounced due to increasing human activities that significantly alter the planet's biophysical properties (Larbi, 2023; Oliveira Júnior et al., 2023).

Growing populations accelerate LULC changes worldwide, placing considerable pressure on natural resources. Consequently, continuous monitoring of LULC is critical for effective resource management and for evaluating climate change impacts (Zafar et al., 2024; Alshehri et al., 2023).

The agricultural sector plays a major role in these changes, which are closely tied to greenhouse gas (GHG) emissions driving climate change (Ma et al., 2023). Understanding how these shifts affect agricultural land distribution is vital for sustainable agriculture and food security (Taiwo et al., 2023). These efforts align with Sustainable Development Goals (SDGs) 2 (Zero Hunger and Sustainable Agriculture) and 13 (Climate Action) under the United Nations' 2030 Agenda. To address these challenges, it is essential to collect LULC data to guide planning and clarify the extent of anthropogenic and natural impacts (Larbi, 2023; Meyfroidt et al., 2022).

One approach is to merge environmental information with spectral data to geolocate these changes (Yuh et al., 2023). Remote sensing techniques allow researchers to obtain LULC data at local, regional, continental, or global scales (Wang et al., 2022) enabling long-term assessments (Illán-Fernandéz et al., 2024).

Advancements in technology now support LULC planning through Geographic Information Systems (GIS), which process remote sensing data and identify distinct LULC types using unique spectral signatures (Taiwo et al., 2023).

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Orbital sensor images are key GIS data sources for observing Earth's surface changes over time (Dimobe et al., 2022). Newer sensors provide multi-temporal availability, broad spatial coverage, and low or no cost, which is especially useful for LULC mapping (Valero et al., 2022). Options include Landsat series (with a 30-m spatial resolution and 16-day revisit), RapidEye satellite constellation (with a 5-m spatial resolution and 24-hour revisit), and PlanetScope (with a 3-m spatial resolution and daily revisit) (Kganyago et al., 2024; Acharki, 2022).

Remote sensing enables LULC mapping for ecological assessments, resource management, rural and urban planning, and climate change studies (Wang et al., 2023). Therefore, the present study characterizes and evaluates spatiotemporal LULC dynamics from 1990 to 2023 in a primarily agricultural region, employing geoprocessing and remote sensing techniques.

MATERIAL AND METHODS

Study area characterization

The study area is in the School of Animal Sciences and Food Engineering (FZEA), University of São Paulo. It is located in Pirassununga, São Paulo State, Brazil (21°55′37″ to 21°59′43″ S; 47°25′30″ to 47°29′33″ W; Figure 1).

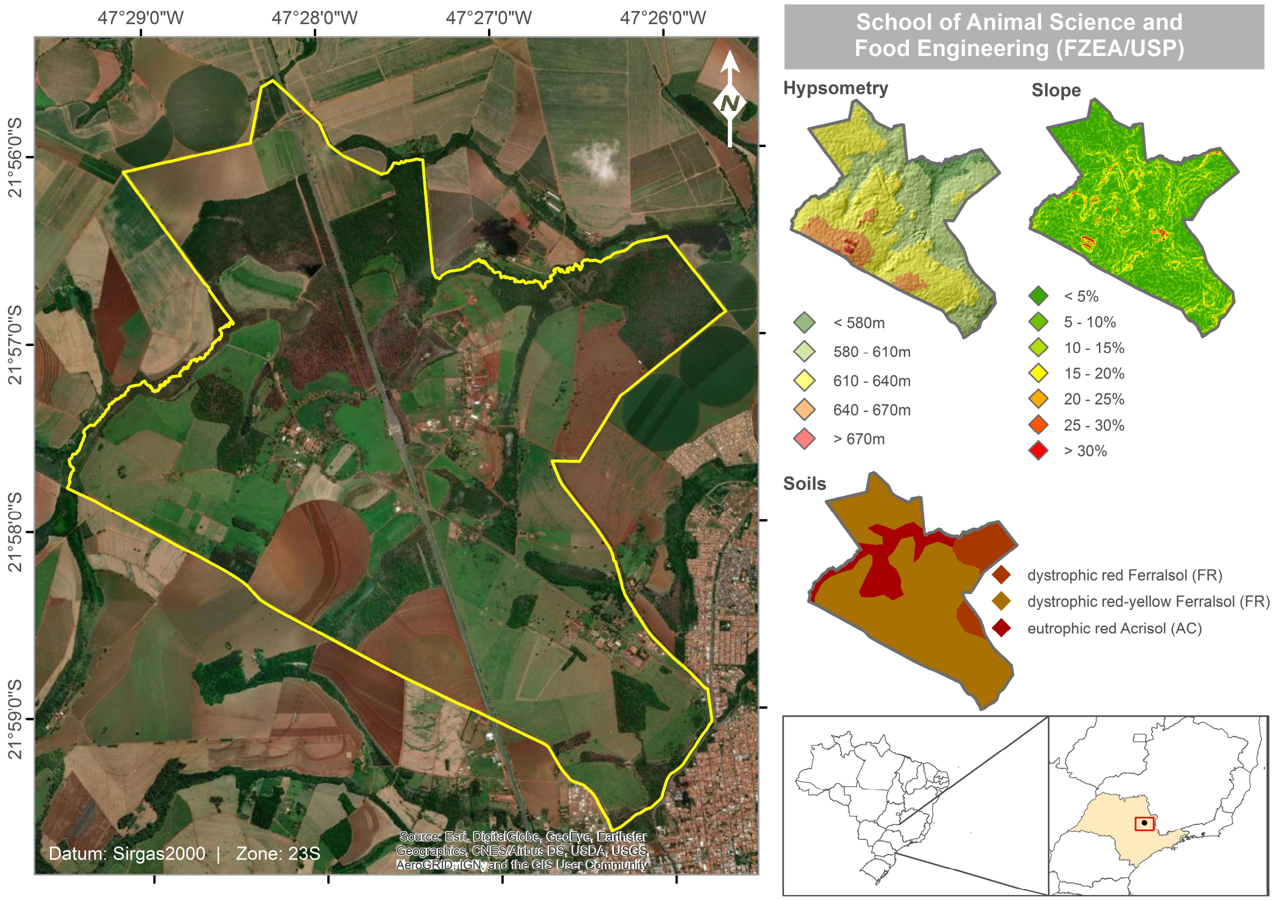


FIGURE 1. Study area location within Pirassununga municipality, São Paulo State, Brazil.

Covering 2,333 hectares, the study area is predominantly composed of medium-textured, dystrophic red-yellow Ferralsol (FR) soils (75.09%). The central portion contains eutrophic red Acrisol (AC) soils with a medium to clayey texture (14.12%), while the far eastern section consists of dystrophic red Ferralsol (FR) soils with a clayey to very clayey texture (10.79%) (Rossi, 2017).

The FZEA has slopes ranging from gentle (less than 5%) to undulating (up to 15%). In terms of hypsometry, the highest elevations (640-670 m) lie in the western region, while the lowest areas are located toward the center-east. According to Köppen classification, the climate is categorized as subtropical *Cwa*, characterized by dry winters (temperatures below 18ºC) and hot summers (temperatures above 22ºC).

Methodological procedures

The methodology includes acquiring satellite images, preparing land use and land cover shapefiles, performing topology analysis, validating land use and land cover maps, and conducting area calculations and spatiotemporal analyses (Figure 2).

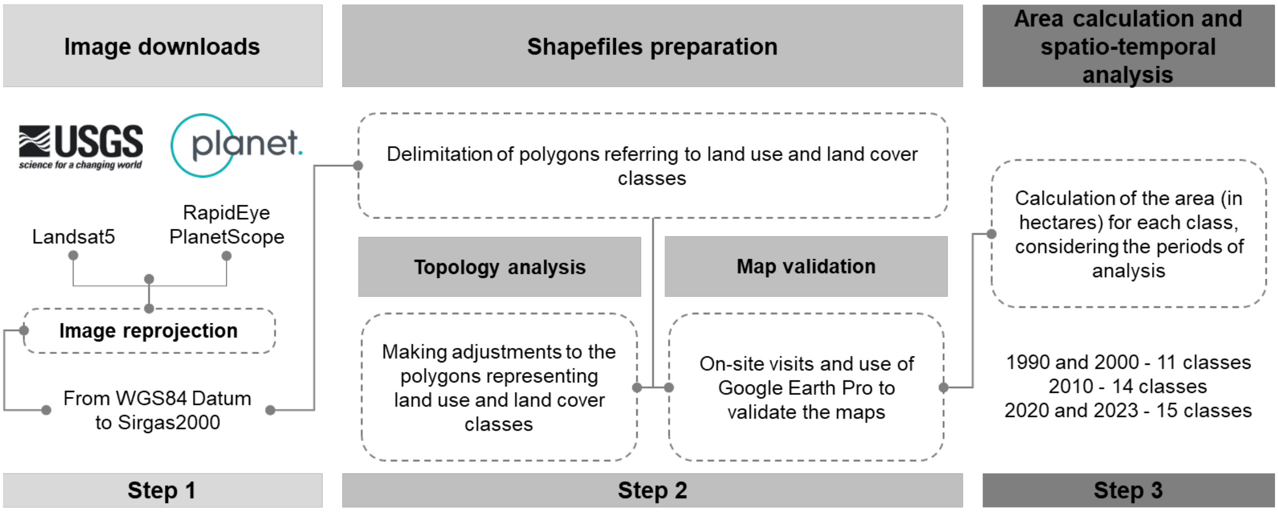


FIGURE 2. Methodological steps to characterize and assess land use and land cover spatiotemporal dynamics from 1990 to 2023, in Pirassununga, São Paulo State, Brazil.

Satellite image acquisition

Landsat 5, RapidEye, and PlanetScope (Planet, 2024) images were acquired free of charge from the USGS Earth Explorer and Planet platforms (USGS, 2024) for LULC mapping. RapidEye and PlanetScope scenes are provided at no cost upon educational registration with the Planet platform, ensuring their use is restricted to scientific research. Table 1 presents the dates and spatial resolutions of these images.

For 1990 and 2000, Landsat 5 images with a 30-meter resolution were used. In 2010, orthorectified RapidEye images at a 5-meter resolution were employed. From 2020 onward, PlanetScope images were used because of their higher 3-meter resolution. Notably, these scenes undergo various levels of processing before they are made available on the respective platforms.

TABLE 1. Scene information used to create land use and land cover maps (1990 to 2023) in Pirassununga, São Paulo State, Brazil.

Orbital Sensor	Date of acquisition	Year	Spatial resolution	Download platform
Landsat 5	28 January	1990	30 m	USGS Earth Explorer
	5 June			
	16 June	2000		
	9 December			
RapidEye	6 February	2010	5 m	Planet
	25 June			
PlanetScope	27 January	2020	3 m	
	20 June			
	26 January	2023		
	10 de June			

The scenes were downloaded in Surface Reflectance (SR) format, which is orthorectified, radiometrically calibrated, and atmospherically corrected (Frazier & Hemingway, 2021). Once added, each raster was reprojected from the WGS84 datum to the Sirgas2000 datum using ArcGIS® software.

Shapefiles and topology analysis

Following scene acquisition and reprojection, polygon-format shapefiles polygon shapefiles were generated in ArcGIS® to delineate LULC classes. For each year (1990, 2000, 2010, 2020, and 2023), maps were created for a single day in the rainy season and one in the dry season, aligning with specified dates.

All shapefiles underwent topology analysis to make minor adjustments, verifying how point, line, and polygon features share coincident geometry (ESRI, 2024). Classification was validated through researchers' technical expertise, Google Earth Pro®, and field visits.

Additionally, map accuracy and agreement were assessed using the Kappa Coefficient, calculated with the "Compute Confusion Matrix" tool in ArcGIS®. A total of 100 polygons were randomly selected for each year analyzed. Google Earth Pro® images confirmed the ground truth data used in the confusion matrices (Table 2). The resulting Kappa coefficients indicated excellent mapping accuracy (Rosner, 2006).

TABLE 2. Kappa coefficients for each year (1990 to 2023) and season (rainy and dry) analyzed in Pirassununga, São Paulo State, Brazil.

Rainy season		**Dry season**	
Date	Kappa coefficient	Date	Kappa coefficient
01/28/1990	0.87	06/05/1990	0.84
12/09/2000	0.91	06/16/2000	0.79
02/06/2010	0.94	06/25/2010	0.86
01/27/2020	0.97	06/20/2020	0.89
01/26/2023	0.95	06/10/2023	0.91

Spatiotemporal analysis of FZEA

Next, a spatiotemporal analysis of the study area from 1990 to 2023 was performed by calculating the percentage variation of each land use and land cover category using Excel®. The goal was to identify which categories underwent the greatest and smallest changes during this period.

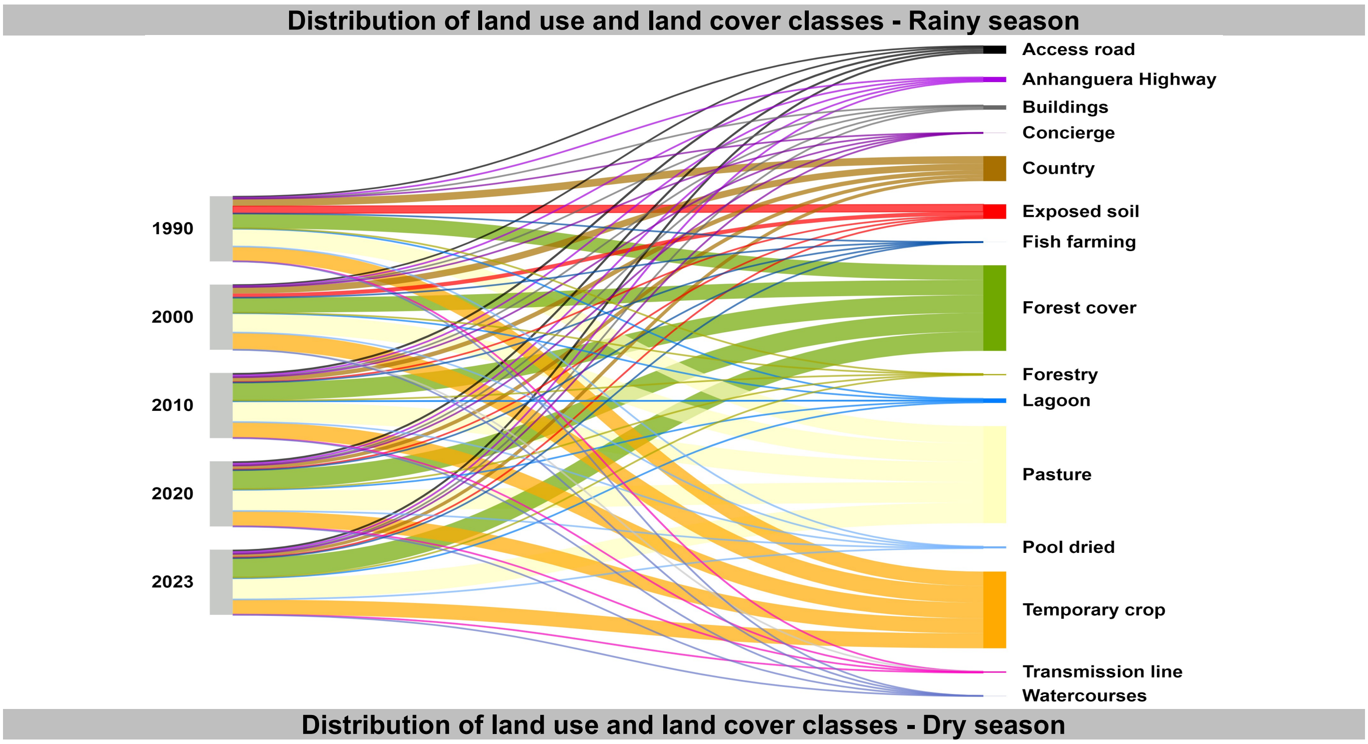
RESULTS AND DISCUSSION

After mapping, it is clear that the study area's land use and land cover (LULC) have changed intermittently over time (Figure 3). Most classes identified in 1990 persisted until 2023, except for artificial drainage channels and certain buildings—such as the dairy, slaughterhouse, veterinary hospital, teaching blocks, and library—which are absent in the Landsat 5 imagery from 1990 and 2000.

This finding can be attributed to two main factors: (1) some structures had not yet been built during 1990 or 2000, and (2) the 30 m spatial resolution of Landsat 5 imagery limited the detection of small features. Spatial resolution is pivotal in remote sensing since coarse-resolution images facilitate large-scale (national, continental, global) monitoring, while higher-resolution data enable more detailed classification and analysis, whether supervised or unsupervised.

In this study, the Landsat 5 images provided limited detail for finer-scale mapping, particularly given the decadal period. Consequently, short-term changes that could influence landscape fragmentation may have been overlooked. For more thorough investigations, higher-resolution data and continuous monitoring are recommended.

At the local scale, fine-resolution images are necessary for effective resource management (Dash, 2024; Obeidat et al., 2019). More detailed LULC data enhance the monitoring of natural resources, anthropogenic activities, and Earth system processes. For instance, Davies et al. (2024) mapped Fiji's LULC (2019–2022) using Sentinel-2 images resampled to a 10 m resolution via bilinear resampling. Carvalho et al. (2021) employed orthorectified RapidEye imagery at 5 m resolution to calculate agricultural water demand in sub-basins in São Paulo, Brazil.



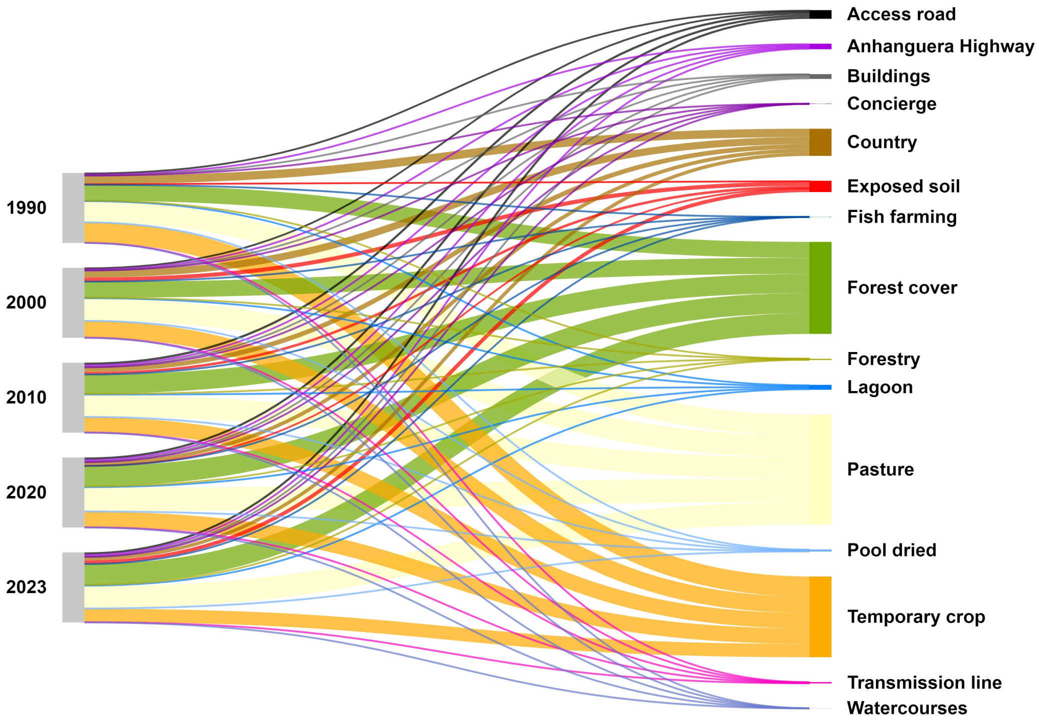
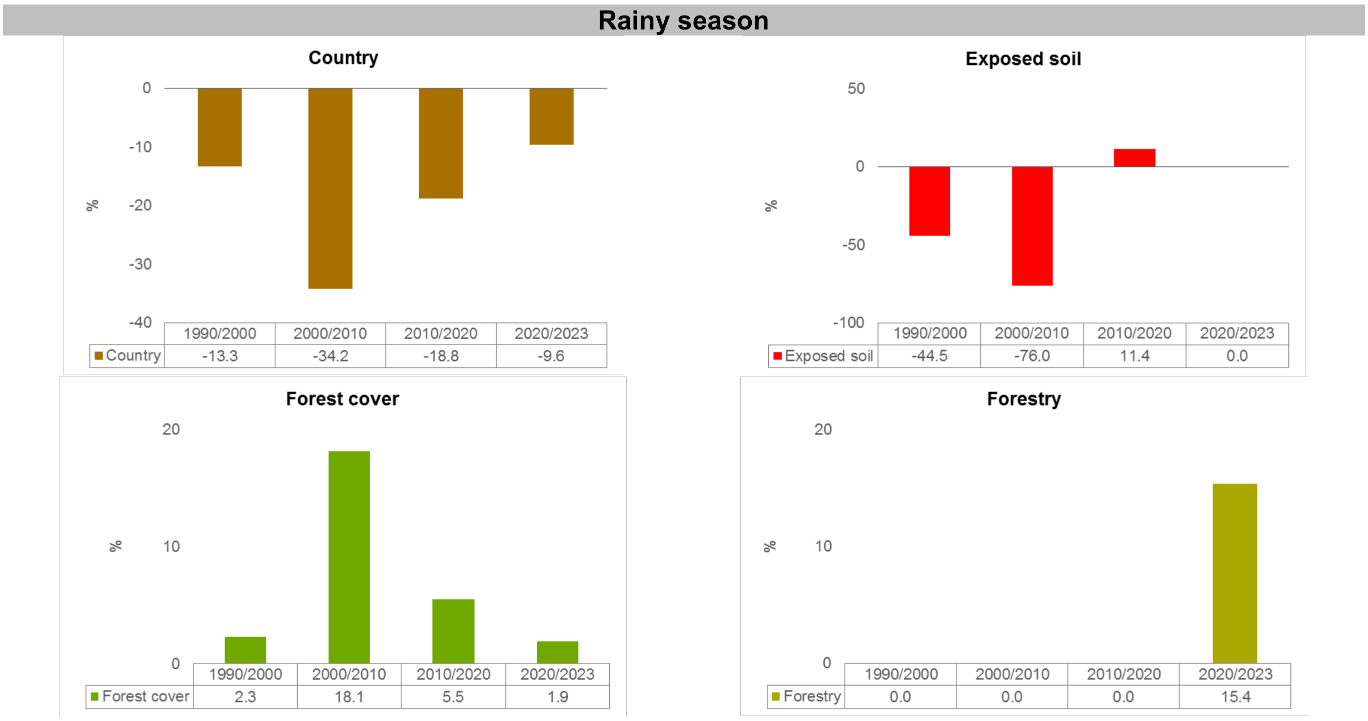


FIGURE 3. Land use and land cover class distribution during the rainy and dry seasons of the years 1990, 2000, 2010, 2020, and 2023 in Pirassununga, São Paulo State, Brazil.

From the 2000s onward (in both rainy and dry seasons), grasslands decreased, whereas forested areas (Atlantic Forest and Cerrado biomes) expanded (Figures 4–7). In the northern and central-eastern regions, temporary crops—principally maize, soybeans, hay, and sorghum in experimental plots—predominate. Notably, these crops often alternate with exposed soil during fallow periods, and pasture areas are sometimes converted to temporary crops.



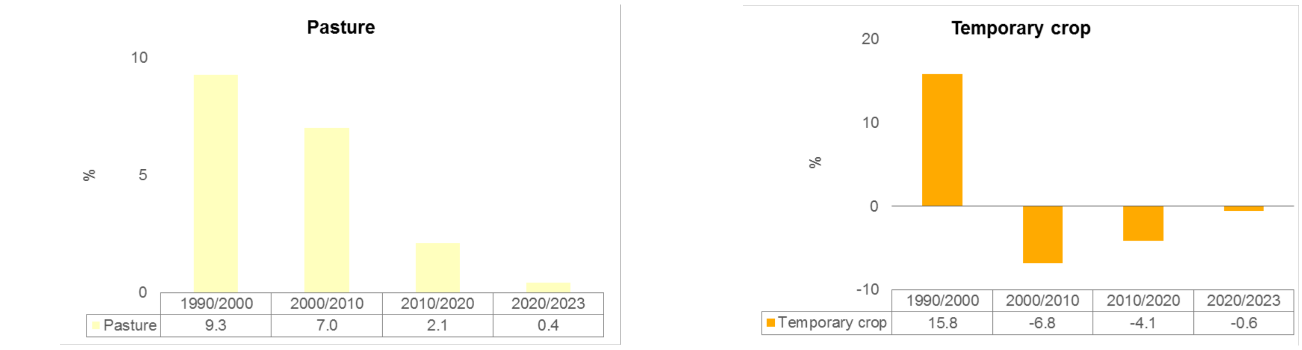


FIGURE 4. Percentage variation in land use and land cover classes showing the greatest changes during the rainy season in Pirassununga, São Paulo State, Brazil.

FIGURE 5. Percentage variation in land use and cover classes showing the greatest changes during the dry season in Pirassununga, São Paulo State, Brazil.

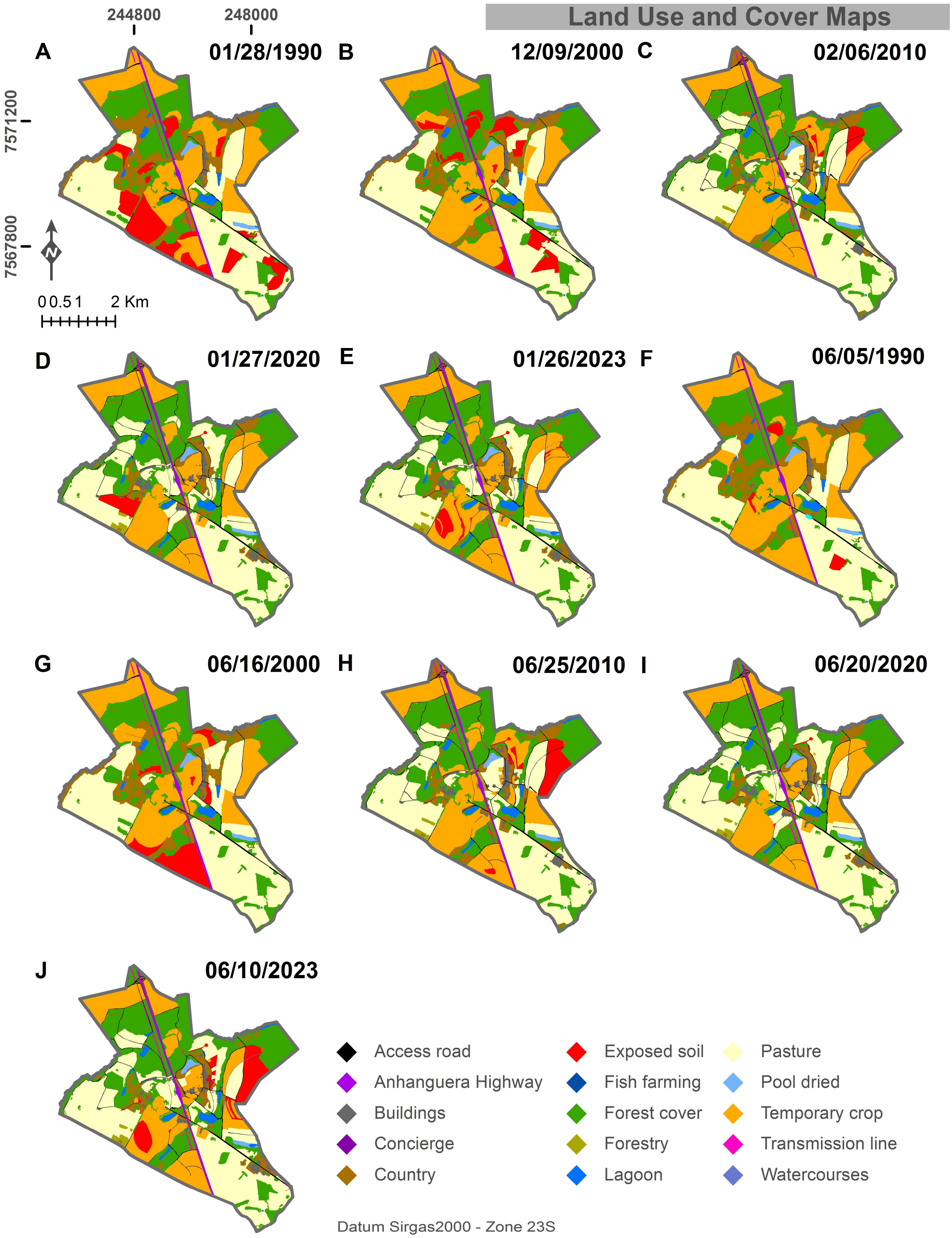


FIGURE 6. Maps of FZEA's land use and land cover during the rainy season (A-E) and dry season (F-J) in Pirassununga, São Paulo State, Brazil.

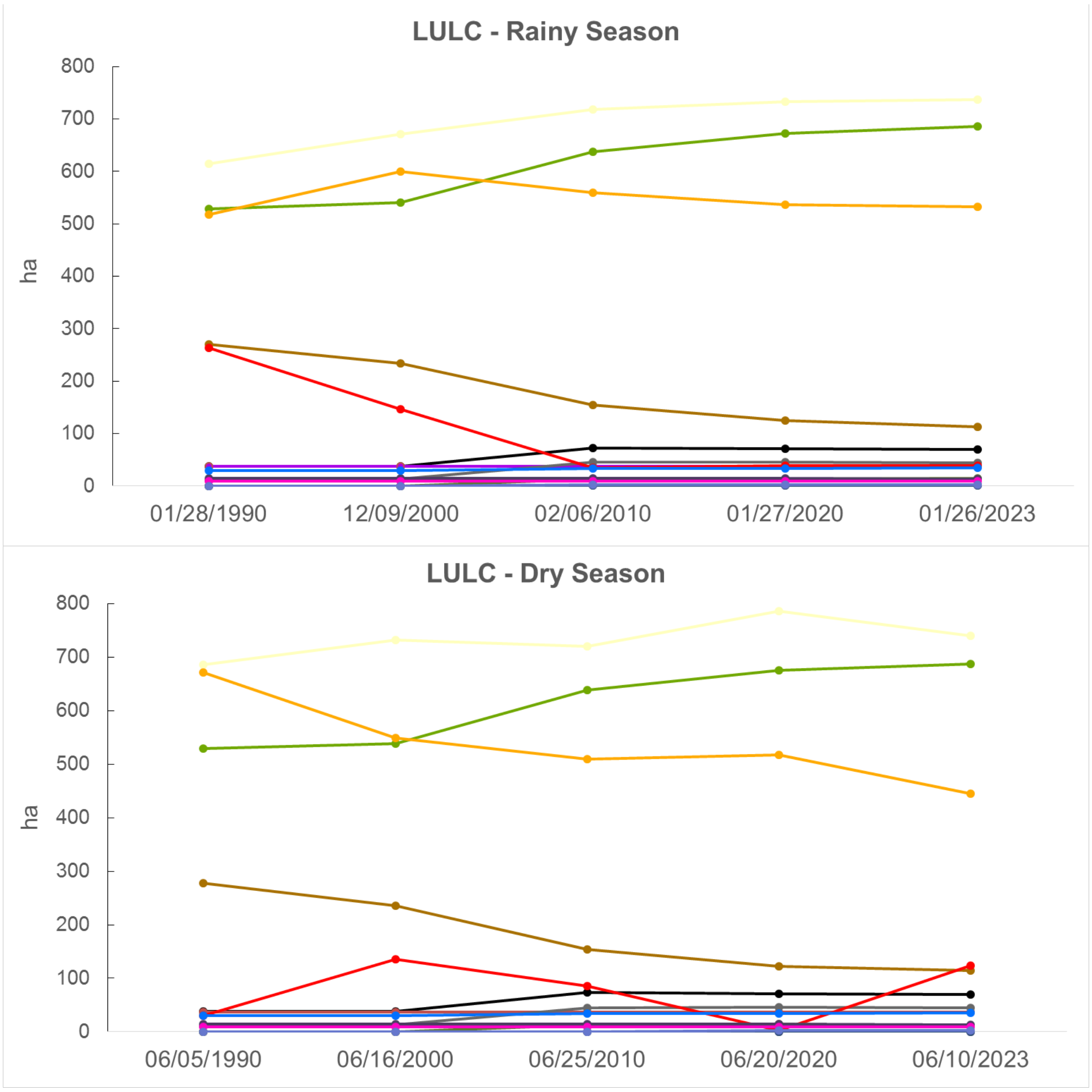


FIGURE 7. Area (ha) occupied by each land use and land cover class (from 1990 to 2023) in Pirassununga, São Paulo State, Brazil.

In the central pivot area (approximately 75 ha), maize and soybean cultivation remained consistent throughout the study period. Surrounding this zone, hay for silage is extensively grown, providing a key feed source for the FZEA herds. Notably, eucalyptus plantations decreased between 2020 and 2023 (dry season) as an extension parallel to the toll plaza on the Anhanguera motorway was removed (Figure 4).

Livestock farming at FZEA employs diverse management practices, including beef and dairy cattle, buffalo, goats, horses, sheep, pigs, rabbits, and fish. The western and southern areas predominantly support beef cattle, while other species are managed within resolute zootechnical facilities on campus.

The LULC changes observed on the FZEA campus are driven by the demands of scientific research, experimentation, and the development of campus-specific infrastructures to meet teaching needs. Consequently, these changes differ from those in regions lacking a professional training and research context. In contrast, LULC changes elsewhere can occur more rapidly due to a variety of environmental, social, and economic factors, such as the need for larger arable areas, urban expansion, road construction, industrial development, reforestation, rehabilitation of degraded lands, among others.

CONCLUSIONS

The methodology of this study allowed for an investigation of land use and land cover (LULC) changes at FZEA in 1990, 2000, 2010, 2020, and 2023. Since the 1990s, the most common LULC classes have been pasture, forest cover, and temporary crops—covering 735, 686, and 533 hectares respectively during the 2023 rainy season. Classes occupying less than 10 hectares include areas with power transmission lines, fish farming, and watercourses.

Monitoring these LULC changes over time in the FZEA field has highlighted specific modifications attributable to its role as an academic and research area governed by campus management policies. To enhance future mapping efforts, the use of unmanned aerial vehicle imagery is recommended. The resulting maps can provide crucial support for managerial planning and decision-making.

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