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Geotechnologies in digital agriculture

Carla Geovana do Nascimento Macário | Júlio César Dalla Mora Esquerdo | Alexandre Camargo Coutinho | Eduardo Antonio Speranza | João dos Santos Vila da Silva | João Francisco Gonçalves Antunes | Laurimar Gonçalves Vendrusculo | Sérgio Aparecido Braga da Cruz

Introduction

Geotechnologies applied in agriculture are increasingly used in Brazil. The monitoring of agricultural crops, surveying and characterizing natural resources, mapping land use and land cover, zoning and evaluating scenarios are some examples that show the presence and the use of geotechnologies. Geotechnology is a specific technology aimed at the acquisition, storage, processing, visualization and analysis of geospatial data, which, in turn permeate, directly or indirectly, a series of themes related to the dynamics of agricultural activity. Remote Sensing, Geographic Information Systems, Global Positioning Systems (GPS) of satellite navigation and Geospatial Database are examples of geotechnologies widely used by various sectors within the particularly diverse agricultural and environmental applications.

The production and availability of geospatial data have increased significantly in recent years. The spread of data repositories and geospatial services on the internet, advances in data processing and storage in computational cloud structures, the expanding use of standards for geoinformation representation, the increase in the number of various types of sensors and for different purposes, and the presence of GPS on mobile devices supporting the georeferenced collection of different types of data are examples that explain the growing use of geospatial data by the society in general. In addition to the vast volume of information, the current context in the production of these geographically located data is characterized by the speed it is produced. Furthermore, the technological advances, georeferenced information and data are increasingly accessible, becoming strategic for decision-making in agriculture and in matters related to territorial management.

Geotechnologies are extremely important in digital agriculture, as they enable verifying temporal and spatial variability, conducting the traceability of production in all links of the chain, as well as monitoring farms, among other functions.

Embrapa Digital Agriculture has worked on this theme over the past few years, including the use, application and development of geotechnologies through a multidisciplinary technical team of the Geotechnology Research Group. This chapter discusses some geotechnologies used by this team in R&D activities, particularly to meet government demands related to agriculture and environment, especially in land management and on the development of computational tools in order to support public policies. The basic concepts about geospatial data are presented, as well as their organization in computational environments, which is a vital and necessary activity in the development of tools for this specific type of data. Next, a brief characterization of an important source of geospatial information is presented: remote sensing, fundamental in various activities for monitoring the earth's surface, which is present in projects and in research initiatives using geotechnologies. Finally, some computational tools based on Geographic Information Systems on the Internet are described, the "WebGIS", intended for visualization and for spatial analysis of geospatial data, and their use in land management.

Applications of geotechnologies in agricultural and environmental monitoring

Geospatial data: basic concepts and their organization

Geospatial data are used to represent real-world phenomena associated with its location on the Earth's surface. This representation is accomplished through three characteristics: spatial, non-spatial and temporal. The spatial characteristic concerns the geographic location of the phenomenon that the data represent and its geometry; the non-spatial characteristic identifies the phenomenon and its properties; and the temporal characteristic informs when the phenomenon occurred. For example, a grain harvester equipped with a yield monitor and a global positioning system can record the amount of grain harvested, the geographic location in the field along the machine's trajectory, while recording the time of periods which the grain inflows into the machine.

The spatial characteristic provides the geospatial data topological and geometric properties. The former is based on the relative positions of objects in space, such as connectivity, orientation, adjacency and containment. The second one represents the geometry of the entities, obtained from their features such as points, lines and polygons. Such properties allow defining the relationships between geospatial data, which are fundamental in geographic applications.

In the agricultural context, geospatial data and their relationships can be used in a variety of activities. For example, on a regional scale, they can be used to represent natural resources, such as rivers, lakes and protected areas close to agricultural projects, and also to represent the dynamics of land use and land cover in the same region over time. At a local scale, on the other hand, they can represent specific characteristics in a farm field, such as the occurrence of weeds and pests, soil fertility or the occurrence of planting failures.

Using this type of data for answering questions related to agriculture requires their computational representation, which can be done through file structures. As the geographic data are spatialized and computationally represented, considering their characteristics and their spatial relationships, different analyses can be performed to provide the desired answers. Geospatial data can be computationally represented by two models: vector and raster, also called raster, as shown in Figure 1. In the vector

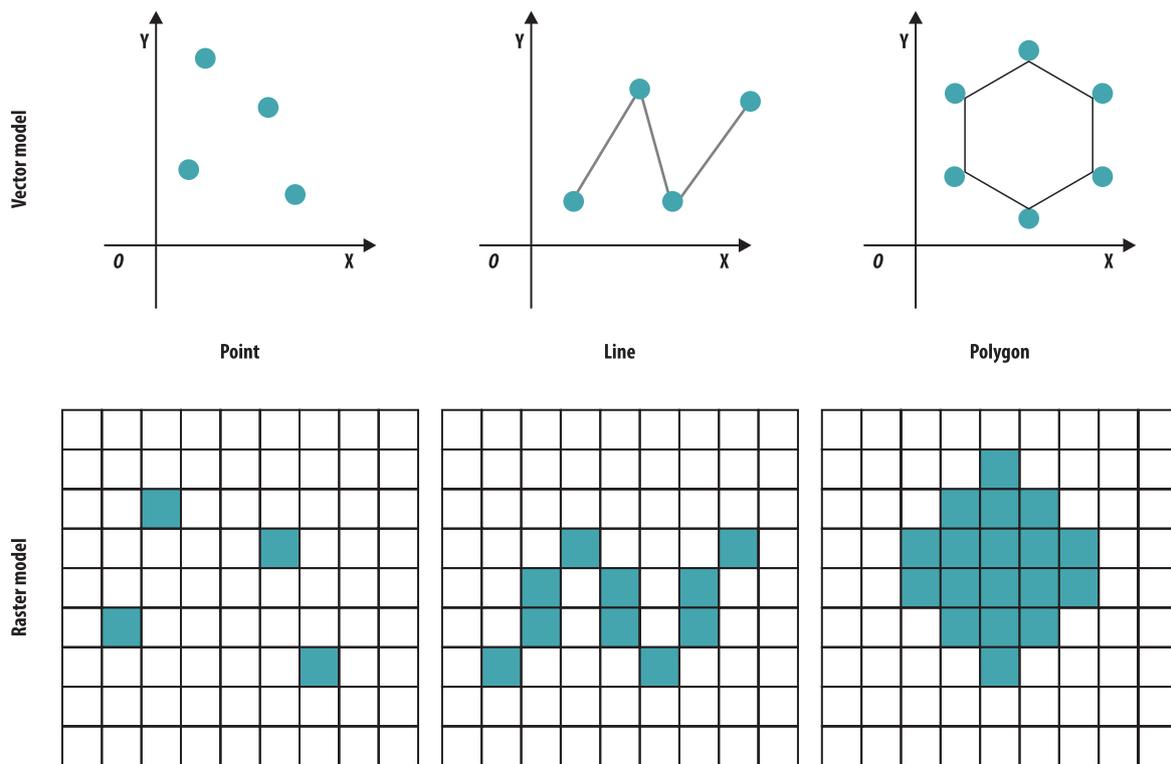


Figure 1. Vector and raster representation models.

Source: Adapted from Li and Yan (2020).

model, the spatial characteristic is reproduced by points, lines or polygons in two-dimensional space, defined in a precise manner with respect to its location, boundary, interior and exterior. Groups of points, lines or polygons can also be used to represent a single phenomenon. In the raster model, on the other hand, space is considered as a regular surface, divided into pixels (picture element) or fixed size cells, representing portions of a territorial area. An important factor in this model is its spatial resolution, calculated based on the size of each cell on the map and the terrain area that the cell can represent.

Large amounts of data, whether geospatial or not, need to be organized for efficient handling. In this regard, we have the concept of Database Management System (DBMS), which are sets of records arranged in a regular structure, which enables data organization and production of information. Geographic Databases work in the same way, and the difference between them is the ability to support geometric features in their tables. In general, traditional DBMS can manipulate geospatial data from spatial modules or extensions. Thus, information is georeferenced, its operations are spatial and, generally, its visualization is cartographic. Examples of spatial extension are PostGIS, present in the public and open-source DBMS PostgreSQL, and Oracle Spatial, present in the Oracle commercial package.

DBMS with spatial extension implements spatial types and operators, in addition to traditional operations, with independence and efficient access, allowing data sharing and redundancy reduction, integrity and security, uniform administration, short-time application development and concurrent access. These characteristics facilitate the developer's task of geographic applications, such as Geographic Information Systems (GIS), which will be discussed in item "Web-based Geographic Information Systems" of this chapter.

The first geographic DBMS efficiently treated only with data represented in the vector model, offering ways of storage and operations for their handling. On the other hand, spatial extensions for treating data

in raster model, such as satellite images, were developed along the time and are now present in various geographic database systems. One example is Well-Known Text (WKT Raster), an extension of PostGIS, which allows for a more efficient and practical way to store and analyze raster data.

The computational organization of geospatial data, whether by a geographic database or by any other type of structure allows them to be handled by different available geotechnologies, such as GIS, WebGIS and remote sensing tools. These technologies will be addressed in the following items in this chapter.

Remote sensing

Several definitions for the term remote sensing can be found in the literature. The American Society for Photogrammetry and Remote Sensing (ASPRS), one of the most important societies that brings together researchers from all over the world on this topic, adopted Colwell's (1983) definition. According to this definition, remote sensing can be understood as the measurement or acquisition of information of some property of an object or phenomenon, by a recording device that is not in physical or close contact with the object or phenomenon under study. According to Jensen (2007), this measurement or acquisition can be performed *in situ* through equipment taken to the field, or more remotely, from equipment installed in suborbital air vehicles, such as balloons, planes and drones, and at orbital level, such as satellites.

Remote imaging sensors are those most commonly found onboard orbital platforms, at altitudes ranging between 200 and 36 thousand kilometers. These sensors transform the electromagnetic energy emitted or reflected by the Earth's surface into an analogical signal, which is processed and converted to build a digital image. Each element that forms the image, called pixel, has a value relative to the amount of energy reflected or emitted by a portion of the Earth's surface. The size of this portion of the observed surface area depends on the sensor's spatial resolution, ranging from centimeters to kilometers, depending on the type and purpose of each instrument.

In addition to the spatial resolution, other sensor characteristics are taken into account when choosing the type of image to be used in each application, such as: temporal resolution, which defines the time the sensor has to revisit the same location; the spectral resolution, which defines the widths and amounts of spectral bands that the sensor is able to "see"; and radiometric resolution, which defines the sensor's ability to distinguish different digital levels, that is, the system's efficiency in detecting and recording differences in the energy reflected or emitted by ground targets.

Currently, there are several sensors in operation onboard orbital platforms developed by governments or private companies, generating products with different surface details, with different passing frequencies and with different acquisition costs. In general, large-scale applications for government purposes make use of freely available public data by official repositories on the internet.

The most successful government program for the remote observation of land resources is the Earth Resources Technology Satellite (ETRS), implemented in the 1970s by National Aeronautics and Space Administration (NASA), the American space agency. This program, which was later renamed Landsat, is responsible for launching eight orbital platforms into space, equipped with imaging sensors of medium-spatial resolution. Launched in 2013, the Landsat-8 is the latest platform from this family of satellites, taking aboard the Operational Land Imager (OLI) sensor. These images are available at a spatial resolution of 30 meters and are processed to remove atmospheric influences (atmospheric correction), as well as terrain distortions effects (orthorectification), in order to improve its radiometric and geometric features, respectively. Another important NASA mission is carried out by the Moderate Resolution Imaging Spectroradiometer (MODIS), sensor aboard the Terra and Aqua satellites, in operation since the early

2000s and which provides data with great periodicity and low spatial detail. Its historical series, which covers a period of more than 22 years of images, is freely available in the form of terrestrial, atmospheric and oceanic products, pre-processed in three spatial resolutions (250 m, 500 m and 1,000 m), derived from 36 spectral bands.

Brazil is also among the countries that produce remote sensing data for monitoring land resources through the CBERS Program (China-Brazil Earth Resources Satellite), the result of the technical-institutional partnership with China, initiated at the end of the 1980s, which involved the National Institute for Space Research (INPE). Currently, the CBERS satellite series, started by CBERS-1 in 1999, has four other satellites, the last one launched in December 2019. CBERS-4A is part of the second generation of this family of satellites and features imaging sensors with different characteristics, producing detailed images between 2 and 60 meters of spatial resolution. The historical series of CBERS images is available at INPE's official repository, one of the forerunners of this policy of publicly and free availability of data through catalogs on the internet.

The availability of high spatial resolution public images has also grown in recent years. In 2014, European Space Agency (ESA) launched Sentinel-1, a satellite equipped with an active imaging sensor (radar). Currently, the Sentinel series has six satellites in orbit. In agricultural monitoring, the most used is Sentinel-2, launched in 2015, which has an onboard the MSI (Multispectral Instrument) sensor that generates images with spatial resolution of up to 10 m in the visible and infrared bands, with revisit every five days, combining good spatial detail and relative observation frequency.

The continuous advancement of technologies in the production of increasingly smaller and more efficient components has represented a trend in the geospatial market with the new generation of Earth observation nanosatellite constellations, such as the private PlanetScope satellites, which offer an unprecedented combination of images with daily temporal resolution and spatial resolution of three meters. Thus, nanosatellites can support the monitoring of agricultural crops that require greater spatial detail, such as coffee and citrus, as well as ILPF systems, which integrate temporary farming, livestock and planted forest in the same production area.

The following topics present initiatives and projects by Embrapa Digital Agriculture and its respective partners, which directly involved the use of remote sensing in the processes of monitoring the earth's surface.

Time series of satellite images and the development of the Temporal Vegetation Analysis System (SATVeg)

In recent years, satellite imagery time series have been increasingly used in a wide range of applications for monitoring the Earth's surface. In remote sensing, the spectro-temporal approach exploits the short revisit time of some orbital sensors aimed at the more frequent acquisition of spectral information from the Earth's surface, bringing advantages over the traditional approach, which is based on a restricted set of images.

In multitemporal analyses for monitoring terrestrial vegetation cover, vegetation indices are commonly used, derived from mathematical combinations between the sensors' spectral bands. These will enhance the presence and vigor of vegetation and reduce the influence of soil and atmospheric factors. The Normalized Difference Vegetation Index (NDVI) and the Enhanced Vegetation Index (EVI), proposed by Rouse et al. (1974) and Huete et al. (1994), respectively, are the most cited in the literature and show a high correlation with green biomass and leaf area. When organized and observed chronologically, these

spectral indices can be used to produce temporal profile charts in order to represent the variations in vegetative vigor over time. Among the most used orbital sensors in multitemporal analysis, MODIS stands out, whose time series of more than 22 years of images has good radiometric and geometric consistency. Figure 2 illustrates a temporal profile example of NDVI, obtained from the MODIS sensor, and the respective interpretation of the land use and land cover dynamics between 2000 and 2018.

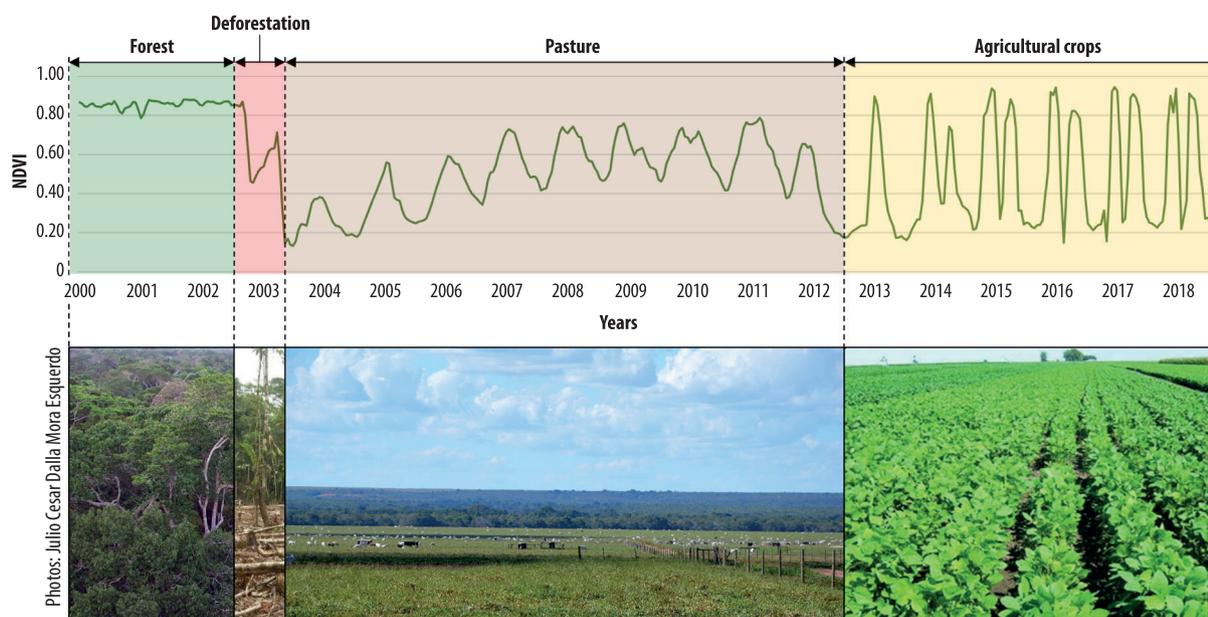


Figure 2. Normalized Difference Vegetation Index temporal profile showing different patterns from transitions in land use and land cover between 2000 and 2018.

Source: Adapted from Embrapa Agricultural Informatics (2020a).

This example enables to identify different behavior patterns of the NDVI temporal profile throughout the historical series, considering the spatial detail of the MODIS sensor images of 6.25 ha (250 m x 250 m). Such variations are due to changes in vegetation cover at a selected point in the state of Mato Grosso. Figure 2 shows that, originally, the area had a natural forest cover, which was deforested at the end of 2002 and occupied by pasture activity until the end of 2012, when it started to be used for temporary agricultural cultivation, with successive cycles of single and double crops. Each segment of the NDVI chart reflects the phenological variations which are characteristic of each type of vegetation cover, which allow to identify the breaks and changes in patterns as a result of the transitions over time.

Analyses based on time series require the acquisition and processing of a considerable volume of data derived from satellite images and involve robust computational activities. Thus, in 2011, Embrapa Digital Agriculture began to develop a Web platform capable of providing temporal profiles of the NDVI and EVI vegetative indices of the MODIS sensor for any location in the Brazilian territory, without the user having to perform the acquisition of images or the execution of any type of processing. Initially aimed at supporting current projects at Embrapa, this Web platform, which was later called the Temporal Vegetation Analysis System (SATVeg), was developed to meet the demand for the immediate supply of temporal profiles of vegetative indices by the internet, from an easy access and visualization platform (Esquerdo et al., 2020).

The system development process went through several phases and involved using different database models to identify the best way to store a large time series of satellite images and, at the same time, allow the instantaneous query and extraction of data from a user-supplied geographic location. The results achieved in these stages proved to be promising and, in 2014, the Embrapa team decided to make the system open to society, free of charge. SATVeg then started to be accessed by a wide-ranging audience, with different interests and purposes of use, stimulating demands for new functionalities. In 2016, with the objective of developing new features, expanding the system's coverage area throughout South America and creating a new visual identity, a partnership with the private sector was initiated, resulting in the current version of the system¹.

SATVeg works very intuitively and can be used by audiences unfamiliar with remote sensing. Figure 3 illustrates the main screen of the system, in which the user interacts with a Google Maps layer to select an area of interest and obtain the temporal profile of the chosen vegetation index (NDVI or EVI), which is shown below the reference map. The system also offers a set of features, such as curve smoothing filters, overlaying layers on the map, pattern library, how-to-use tutorial, among others.

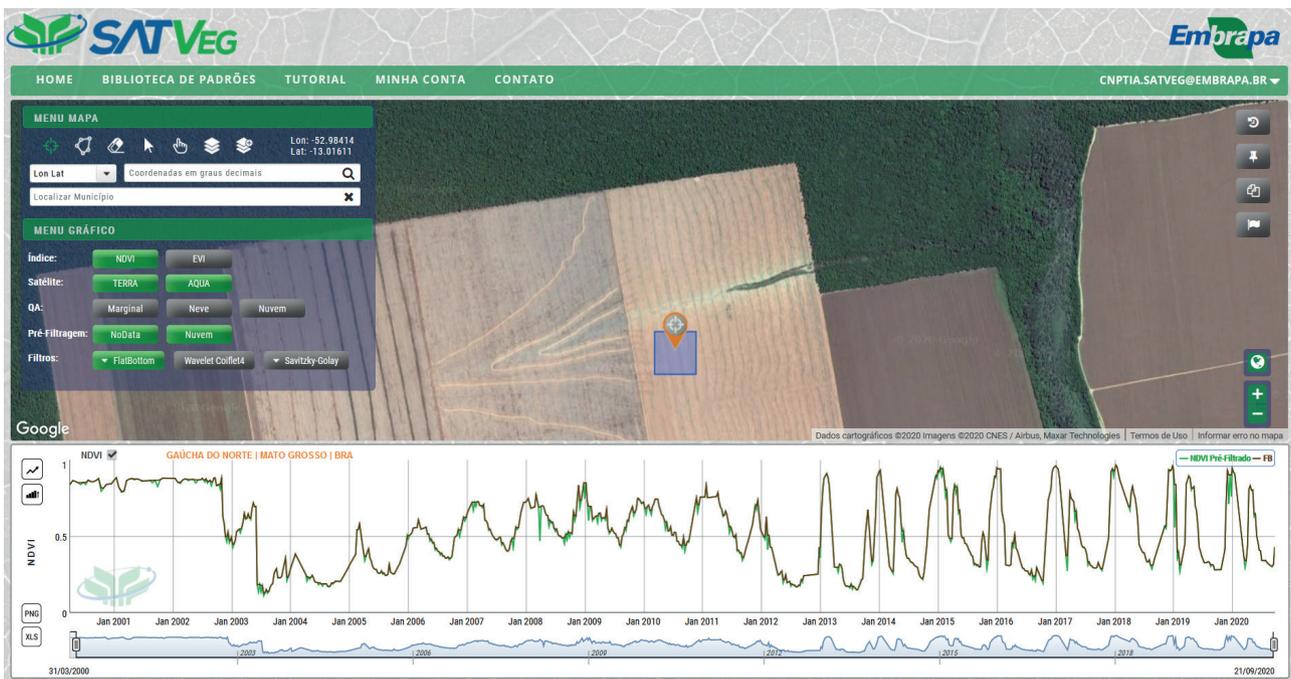


Figure 3. Temporal Vegetation Analysis System (SATVeg) main screen.

Source: Adapted from Embrapa Agricultural Informatics (2020a).

With more than 14 thousand registered users at present, SATVeg has supported several land surface monitoring activities, such as large-scale land use and land cover mapping projects, monitoring of the productive potential of agricultural crops, detection of deforestation, inspections, among others. SATVeg was recently included in the Central Bank of Brazil under Ordinance no. 4,796 as a remote tool to support proof of agricultural losses under the Agricultural Activity Guarantee Program (Proagro), as the system can indicate the conditions of green biomass from crops, and support decisions on issues related to agricultural insurance payment.

¹ Available at: www.satveg.cnpia.embrapa.br

Developed using free software, the SATVeg database has been periodically fed with new images from the MODIS sensor, and Embrapa Digital Agriculture has kept the software components updated. An Application Programming Interface (API) was also developed to programmatically provide the system data, in order to feed third-party systems that make use of the temporal profiles of the vegetation indexes in several other applications.

Land use and land cover monitoring – TerraClass Project

The theoretical bases of sustainable development presuppose public actions and policies to promote economic development, synchronized with guarantees for the preservation of natural ecosystems, their biodiversity and their services. In Brazil, a country with one of the largest tracts of unexplored arable land on the planet, the expansion of the agricultural frontier and the technological development of agricultural activities have been accompanied by intense national and international debates on this topic.

Concerned with the negative impacts on the agricultural commodities market, generated by the release of data which showed that agriculture was rapidly advancing on the Amazon forests, the Federal Government asked Embrapa and INPE, public institutions with accumulated knowledge and competence on the subject, to produce, based on scientific and impartial data, a new vision on the land use and land cover in the deforested areas of the Legal Amazon. As a result of this institutional mobilization, the TerraClass Amazon Project emerged (Almeida et al., 2016), to systematically produce maps related to land use and land cover in the region, allowing to monitor the impacts of actions, and public policies of the Federal Government focused both on the development and intensification of agricultural activity and the preservation of natural systems.

Developed and implemented by federal institutions, TerraClass generates official data on the dynamics of land use and coverage, fundamentally expanding the management capacity in the Amazon territory and reinforcing national sovereignty over a region with explicit disputes between sectors, agents and actors, national and international, whose interests are driven by economic, social and environmental issues, among others.

Currently, seven mappings are available, referring to the base years 1991, 2000, 2004, 2008, 2010, 2012 and 2014, carried out by the technical teams of Embrapa Digital Agriculture, Embrapa Eastern Amazon and the Regional Center of the Amazon (CRA/INPE). To organize, store and make them accessible to users, Embrapa Digital Agriculture has developed a free public access portal, presented in topic “Interactive Environmental Licensing Support System (SISLA)” of this chapter.

The area covered by the maps covers the entire extension of the Legal Amazon, although the identification of thematic classes is carried out by satellite imagery only in the deforested areas mapped by the Program for Deforestation Monitoring in the Brazilian Legal Amazon (PRODES). The thematic classes covered by TerraClass are presented in Table 1.

The mappings were carried out at a scale of 1:100,000 (each centimeter on the paper map is equivalent to one kilometer in the real world) from public images with varied spatial detail. The main image base is formed by scenes from the Landsat satellite, with a spatial resolution of 30 m. Time series of MODIS images, with spatial resolution of 250 m, were also used in the mapping process of the temporary agriculture class.

Different methods were used in the mapping activities of the thematic classes, according to the complexity of the targets and the technical knowledge of the institutions involved. These methods used different types of approaches, from the most complex, based on machine learning techniques, to the most simple and laborious approach, such as the visual interpretation of images. Temporary agriculture,

Table 1. Thematic classes mapped by TerraClass.

Classes	Description
Temporary agricultural crop	Agricultural crops that present one or more production cycles in the reference crop year mapping, such as soybeans, corn, cotton, among others.
Semi-perennial agricultural crop	Agricultural crops that present a larger production cycle than the reference crop year mapping, mainly represented by sugarcane.
Perennial agricultural crop	Permanent agricultural crops, with different stages of maturity and vegetation cover, such as coffee, citrus, rubber plantations, among others.
Cultivated arboreal shrub pasture	Pastures with a predominance of woody vegetation, composed of shrub or arboreal species, in addition to cultivated herbaceous species.
Herbaceous cultivated pasture	Pastures with predominance of herbaceous forage vegetation, composed of cultivated species.
Silviculture	Forest species of commercial interest, represented by monospecific tree formations, such as eucalyptus and pine.
Secondary natural forest vegetation	Natural vegetation in the process of regeneration, characterized by the densification of tree species that have already undergone total original vegetation suppression since the beginning of deforestation monitoring in the Amazon.
Mining	Mineral extraction areas characterized by the presence of bare soils and changes in the local landscape.
Urban area	Urban stains as a result of population concentration that form villages, towns or cities that present an infrastructure different from the rural area, presenting densification of streets, houses, buildings and other public facilities.
Other urbanized areas	Areas with differentiated infrastructure, with less density of streets, houses and other industrial equipment such as sheds, mills, warehouses, among others.
Water bodies	Natural water bodies such as rivers, lakes, dams and dams.
Others	Areas that do not fit into the other thematic classes, such as rocky outcrops, fluvial beaches, sand banks, among others.
Not observed	Areas not mapped in the satellite images used due to the presence of clouds or burned areas.
Deforestation of the year	Areas whose natural vegetation cover was removed during the reference year mapping.

Source: GeoPortal TerraClass (2020).

which presents high spectral dynamics and occurs in specific periods of the year, was mapped using the spectral-temporal approach, addressed in item “Time Series of Satellite Images and the Development of the Temporal Vegetation Analysis System” of this chapter. Here, machine learning-based classifiers were trained with field samples and applied to a time series of vegetation indices to detect targets with specific temporal behaviors. The secondary vegetation areas were mapped based on a Linear Spectral Mixture Model (LSMM) applied to the deforestation areas to identify the vegetation, soil and shade fractions and to separate the secondary vegetation areas from the others. As for other types of thematic classes, such as pastures, forestry, mining, urban areas, and others, identification and mapping were done based on visual interpretations of Landsat images, due to the wide variation in patterns and the difficulty to automate a classification method.

Due to the strategic nature of the information produced by TerraClass throughout the historical series of mappings for the Legal Amazon, the Federal Government requested expanding the coverage area

of the mappings for the Cerrado biome, another territorial portion strongly pressured by agricultural expansion and monitored by national and international organizations. To meet this demand, a new institutional articulation, which involved research, development and innovation institutions, universities and government agencies, was consolidated to carry out the mapping of land use and land cover of the Cerrado biome, referring to the base year 2013. Currently, new versions of TerraClass Cerrado, referring to the base years 2018, 2020 and 2022, are being carried out to update the mappings and to form a historical series that allows analyzing the dynamics of land use and coverage in that biome.

Since the first demand initiated by the Federal Government, there has been a constant and significant advance in the area of information technology, both with regard to new sensors embedded in satellites, planes, drones, and others, as well as new storage devices, processing, analysis and distribution of digital data and information. Thus, a large part of the efforts and focus of the TerraClass coordination and execution team has been directed towards updating the data from the historical series of the Amazon and Cerrado mappings, expanding the mappings to other Brazilian biomes and promoting greater automation of mapping processes, in order to provide significant reductions in the cost and execution time.

GeoMS Project

From 2007 to 2012, the government of Mato Grosso do Sul state, Embrapa Digital Agriculture and partners developed the GeoMS project in order to structure a geo-referenced information system to monitor the rural space. This could help state governments improve their decision-making efficiency to implement strategic projects, using the state of Mato Grosso do Sul as a case study. This demand came from specific needs of the state, such as mitigating problems associated with climate change, avoiding the waste of natural resources and reducing deforestation and carbon emissions. The initiative also originated from the concern with issues inherent to sustainable development and conservation of the environment, as well as seeking to improve the state's environmental management system, making environmental licensing processes and procedures more efficient and transparent.

Throughout its term, the GeoMS teams developed and implemented the Interactive Environmental Licensing Support System (Sisla), a web-based geographic information platform intended to organize the geospatial data from the state of Mato Grosso do Sul and decision support, which is presented in item "Interactive Environmental Licensing Support System (SISLA)" of this chapter. Considering that the system was developed to provide reliable information to support environmental licensing, it was necessary to map the land use and land cover, as well as to detail the water resources data in the whole state, activities strongly based on the use of remote sensing.

The mapping of deforestation and the land use and land cover was carried out on a scale of 1:100,000 for the year 2007, considered ground zero in the monitoring process of this type of information in the state of Mato Grosso do Sul. The activities were carried out by Embrapa Digital Agriculture using CBERS satellite images from the High-Resolution Imaging Camera (Charge Coupled Device – CCD), with a spatial resolution of 20 m, aboard the CBERS-2B platform. The mapping was individualized into 64 classes (Silva et al., 2011a) at level III, according to the Brazilian vegetation classification system, which can be aggregated into 15 classes of phytophysionomies, considered level II, namely: 1- Riparian Vegetation (tree, shrub, herbaceous); 2-Seasonal Semideciduous Forest; 3-Deciduous Seasonal Forest; 4-Savanna Cerrado; 5-Savanna Steppe (chaco); 6-Pioneer Formations (tree, shrub and herbaceous); 7-Floristic Contacts (ecotone and enclave); 8-Vegetational Refuges (relic communities); 9-Secondary Vegetation; 10-Annual Agriculture; 11-Agriculture; 12-Semi-perennial Agriculture; 13-Forestry; 14-Livestock (planted pasture); and 15-Other Anthropogenic Areas (urban influence, mining, occupied floodplains).

Special attention was given to the identification and mapping of cultivated pastures, which in the state of Mato Grosso do Sul represented 16 million hectares. Of these, about 57% were in different stages of degradation, which significantly affected the livestock economy, requiring a recovery process through revegetation work or enrichment of the area (Silva et al., 2011b). Thus, according to degradation, four levels of pasture were identified and mapped on a scale of 1:50,000, in sample areas: non-degraded (I), moderate degradation (II), strong degradation (III) and very strong (IV). This activity involved merging images of HRC sensors (High-Resolution Camera or High-Resolution Panchromatic Camera) with 2.5 m of resolution and CCD, both aboard the CBERS-2B satellite.

The information on water resources in the state of Mato Grosso do Sul was also updated and improved based on remote sensing data, at a scale of 1:100,000. This process included updating the drainage network and detailing the territorial limits of the Planning and Management Units of water resources, as well as creating slope maps, based on the classes defined by the National Council for the Environment (Conama). Such information, in addition to supporting the spatial analysis of the surroundings of the project whose licensing was requested, also helps other sectors or areas of the government. For example, altimetry and slope data assist in the application of the Brazilian Forest Code in relation to Permanent Preservation Areas (APP) on slopes and hilltops; the delimitation of watershed basins or planning and management units and the updating of the drainage network assist in applying the state water resources plan. Both are also inputs for the elaboration of the Ecological-Economic Zoning (ZEE) of the state.

Another important result of the GeoMS project included training the team at the Mato Grosso do Sul Environment Institute (Imasul), in order to use Sisa and to use satellite images and mapping of vegetation cover and land use. The results are widely used by managers, consultants, environmental inspectors, environmental analysts, entrepreneurs, researchers, teachers, students, among others.

Web-based geographic information systems

GIS has been used for many years to support environmental decisions, providing users with easy visualization, storage and analysis of geospatial data. This is its main difference in relation to conventional information systems: its ability to store both descriptive attributes and geometries of the different types of input data (Casanova et al., 2005). Through GIS it is possible to insert and integrate, in a single database, textual spatial information, satellite images, data obtained from GPS, vector grids and thematic maps, in addition to offering mechanisms to combine this information and provide spatial analysis, whose results can guide decision making in various applications. This tool is available in various computer packages, with commercial and free options, compatible with various raster and vector data.

Over the years, GIS has incorporated new technologies and adopted innovative architectures, following the evolution of the areas of computing and system development. It was from this evolutionary process that Web Geographic Information System (WebGIS) emerged, whose purpose is the same as conventional GIS, but which can be accessed through an internet browser. In a WebGIS, the information system is implemented in the client-server architecture, in which the “server” part is responsible for the processing and storage of geospatial data and the “client” part corresponds to a web browser, which presents an interface for visualizing the data and interaction with the system (Smith et al., 2020). An important feature of a WebGIS is the way communication is executed between the client’s graphical interface and the server’s geographic DBMS, which stores geospatial information. Therefore, an intermediary layer is used between the application and the geographic DBMS, which basically consists of map servers. These servers can be seen as APIs capable of collecting data directly from geographic DBMS and delivering them, in a standardized way, to the application accessed by the end user through services such as those

implemented by the Open Geospatial Consortium (OGC). Thus, map servers allow the use of the same set of geographic data by different applications.

With the adoption of this client-server architecture, WebGIS enables access to its resources by any user connected to the internet, without having to install specific programs on their computer or acquire geospatial databases. A WebGIS can be characterized both as a tool for the generic treatment of geospatial data, similarly to a traditional GIS, or as an environment for exploring a pre-defined data set, which allows to carry out operations designed to meet specific user profiles.

Regarding this topic, we present some WebGIS solutions developed under the coordination of the technical team of Embrapa Digital Agriculture to meet government demands related to the monitoring of land use and land cover, environmental licensing and the organization of geospatial information for the ZEE of the Amazon states.

GeoPortal and WebGIS TerraClass

The current collection of maps of the TerraClass Project, presented in item “2.2.2 Land use and land cover monitoring – TerraClass Project”, supports the formulation of public policies, territorial management and actions related to the preservation of national biodiversity, and the maintenance of the quality of ecosystem services from different sectors of civil society and the Federal Government. The mappings have been available on the internet since their release, but in raw format, which required users to download them to a computer and use a GIS to process and analyze them. Furthermore, considering the very diverse audience of users for this type of information, not always familiarized with geoprocessing, there was a growing demand for the development of user-friendly tools that could provide simple mechanisms to analyze territorial dynamics in the Legal Amazon.

Given the large volume of existing geospatial data, as well as operational difficulties that required previous computational processing to organize and adapt the data to the users’ areas of interest, the GeoPortal TerraClass was developed (Figure 4). This digital platform consists of: a landing-page with a



Figure 4. Landing-page of GeoPortal TerraClass.

Source: GeoPortal TerraClass (2020).

general presentation of the TerraClass Project; description and characterization of the legend of thematic mapping classes; a mechanism for downloading the raster or vector data, in different geographic areas; and access to WebGIS TerraClass, which is a technology to facilitate analysis on the computer screen.

WebGIS TerraClass (Figure 5) is a web-based geoinformation system that provides interactive tools for visualization, analysis and interoperability of geospatial data on land use and land cover identified in deforested areas of the Legal Amazon. The system is intended for the common user up to the technician with advanced knowledge in geotechnologies, providing simple comparisons and complex spatial analysis across the entire historical series of available mappings. To use the tools, the user must select an object associated with the available land areas, which can be from the entire Legal Amazon, Federation Units, Municipalities or Water Planning Units (UPH).

The visualization tools allow to select the land use and land cover mapping year; compare side-by-side mappings between pairs of years by scrolling the map with a slider that shows each year on one side of a vertical line; and observe mapping details by increasing the approximation in a given area of interest.

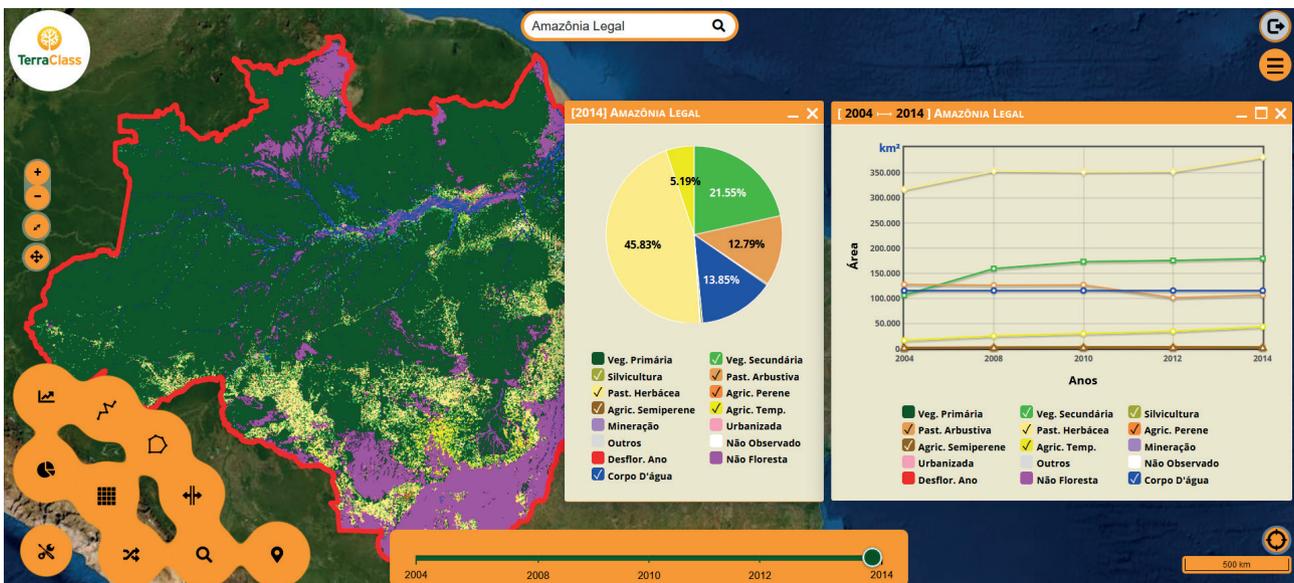


Figure 5. WebGIS TerraClass featuring the 2014 mapping pie chart and the 2004 to 2014 evolution chart for the Legal Amazon.

Source: GeoPortal TerraClass (2020).

The analysis tools generate graphs of map sectors that represent all classes of land use and land cover by slices proportional to their respective frequencies; transition matrices that presents the probabilities of land use and land cover classes to remain in the same classes or to change to other ones, showing the temporal dynamics in any combination between pairs of years; transition diagrams based on Sankey's flowchart (Schmidt, 2008), in which nodes constitute the area of a given thematic class in a year, and the edges represent the flow of area transitions between classes over the years, enabling the spatialization of changing areas on the screen ; and the evolution graph, that shows the variation of the area of all thematic classes across the historical series of mappings.

Figure 6 exemplifies the Sankey transition diagram for the state of Mato Grosso based on the selection related to the years 2004, 2010 and 2014, enabling a detailed analysis of land use and land cover transitions during the period. The transition values between thematic classes of interest can be observed by positioning the cursor over the lines. In this example, the line highlighted in cyan represents the

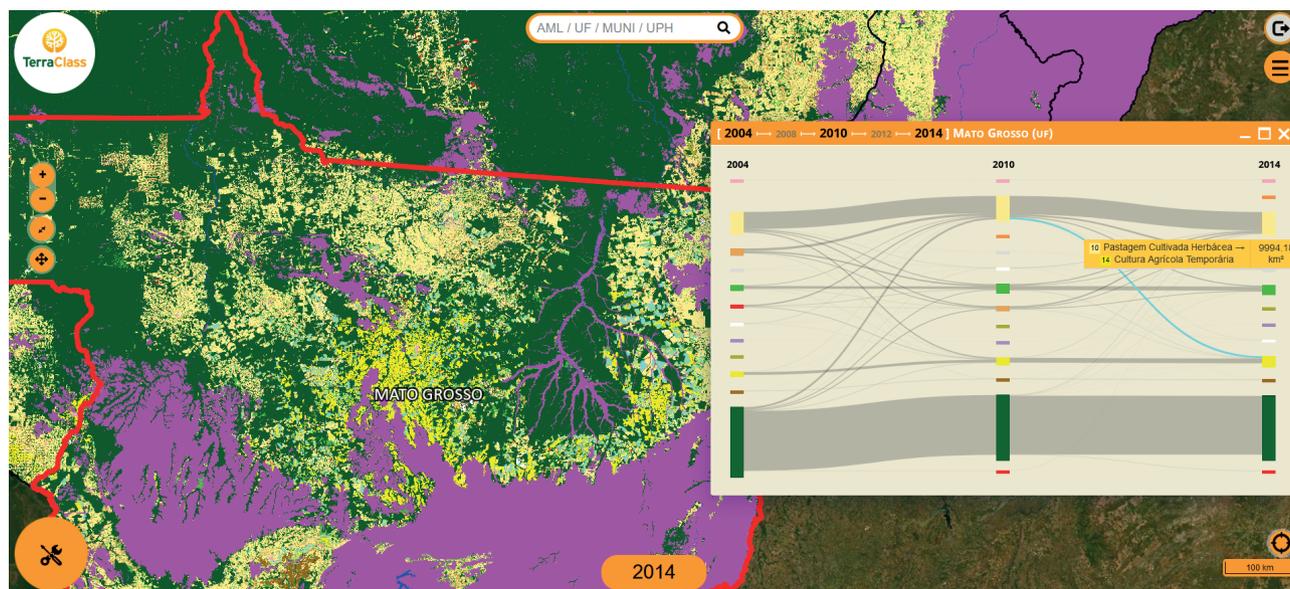


Figure 6. Sankey transition diagram generated for the years 2004, 2010 and 2014 in the state of Mato Grosso.

Source: GeoPortal TerraClass (2020).

change of 9,948.18 km² from the Herbaceous Cultivated Pasture thematic class in 2010 to the Temporary Agricultural Crop class in 2014, which also appears spatialized over the 2014 mapping with the same color, indicating the increase in agricultural areas associated with the conversion of areas previously destined for livestock.

The TerraClass WebGIS has interoperability with SATVeg, accessed by selecting a point in the map, which automatically activates an application integration bridge and which will display in SATVeg the temporal profile of MODIS vegetation index in the respective geographic location, expressing changes in plant green biomass over time.

The TerraClass GeoPortal² and its target audience is data users who need to know and analyze the dynamics of land use and cover in the deforested areas of the Legal Amazon, with a focus in territorial management such as public managers, researchers, teachers, students, self-employed professionals, extension workers, association of producers, rural unions, among others.

Interactive Environmental Licensing Support System (SISLA)

The Interactive Environmental Licensing Support System (SISLA) is a WebGIS application that allows the collection, organization, integration and management of georeferenced information related to environmental licensing processes by governmental agencies. The main objective of this application is to enable governmental agencies to fully monitor the environmental licensing process in its various stages, ranging from georeferenced analysis around the enterprise requesting the licensing, in order to support decision-making. The greatest benefit provided using applications such as SISLA is the ability to provide greater flexibility, transparency and security in the procedural protocols, as the analyses are based on official government data and are freely available in the application itself. Thus, the applicant requesting an

² Available at www.terraclass.gov.br

environmental licensing can check, via the internet, whether or not this enterprise is in geographical and environmental compliance, even before submitting the process to the responsible government agency.

SISLA³ was implemented in Mato Grosso do Sul in October 2008, when the state started to use a WebGIS as a supporting tool to analyze processes involving environmental licensing requests for activities in sectors such as infrastructure, agropastoral, mining, tourism, industry, sanitation, fishing, fauna and forests.

Specifically for the agropastoral sector, activities such as construction of dams, establishing irrigation infrastructure, feedlots for cattle, horses, sheep and goats, and the construction of silos, warehouses and tanks for aquaculture are subject to environmental licensing in the state of Mato Grosso do Sul, as defined by the Mato Grosso State Institute of Environment (IMASUL).

The development of SISLA included the use of free software focused on the geotechnology theme, such as I3Geo (Speranza et al., 2011; Brazilian Public Software, 2020). This allows its adaptation, at low cost, to the demands and local needs of each government, and also its integration with corporate systems for the procedural protocols. The main module of the system – the analysis and generation of the project's surroundings report – allows the applicant requesting an environmental licensing to send its property's georeferenced maps, which contain the enterprise's boundaries, permanent protection areas and related issues, in accordance with the regulation by the government agency. Based on these maps, SISLA performs geospatial queries to verify the proximity or intersection of the project/enterprise boundaries with the areas protected by the government, such as indigenous lands and conservation units, in addition to slope analyses for the areas in the project (Figure 7), generating spatial analysis reports (Figure 8).

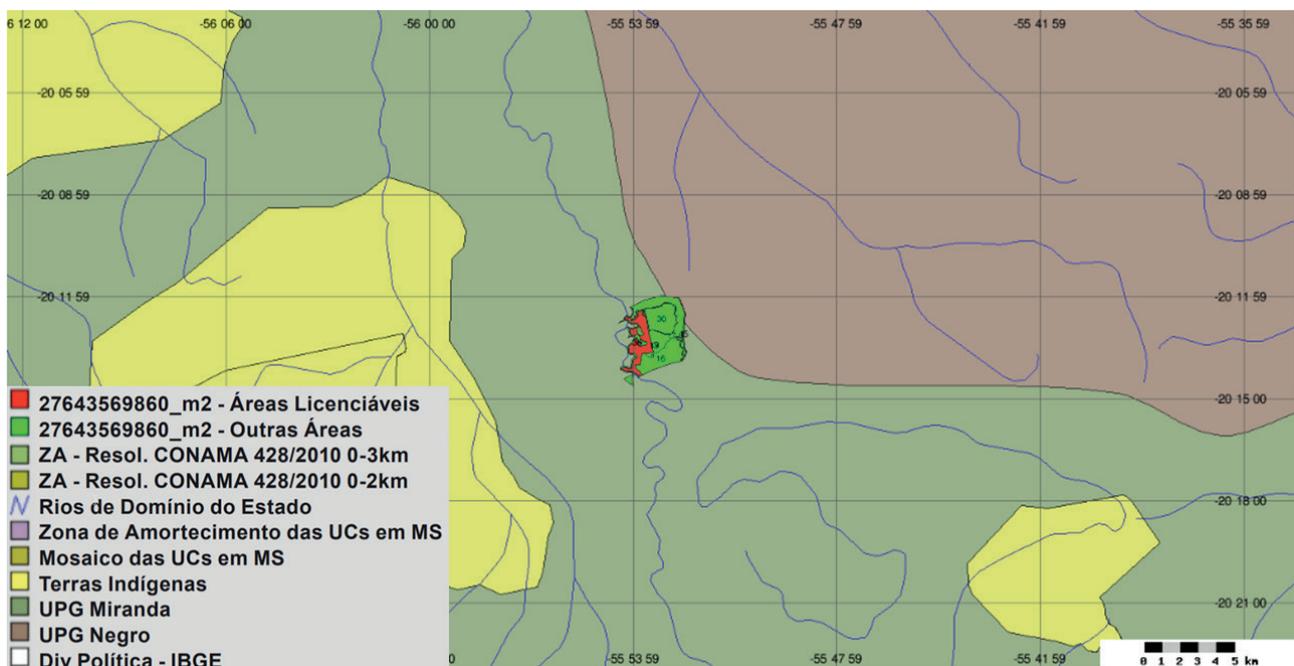


Figure 7. Map containing the property boundaries and the areas protected by the government.

Source: Silva et al. (2011b).

³ Available at: sisla.imasul.ms.gov.br

Conservation Units, Indigenous Lands, Buffer Zones, ZAs (Conama Resolution 428 0-2km) and ZAs (Conama Resolution 428 0-3km) inside the property

	Name	Distance
Nothing found		

Conservation Units, Indigenous Lands, Buffer Zones, ZAs (Conama Resolution 428 0-2km) and ZAs (Conama Resolution 428 0-3km) that fully contain the property

	Name	Distance
Nothing found		

Conservation Units, Indigenous Lands, Buffer Zones, ZAs (Conama Resolution 428 0-2km) and ZAs (Conama Resolution 428 0-3km) close to 15 km from the property

	Name	Distance
Conservation Units		
Nothing found		
Indigenous Lands		
Taunay-Ipegue	36 - Project Area for Provisional Legal Reserve Registration (APTAP)	11.012 km
Taunay-Ipegue	36 - Project Area for Provisional Legal Reserve Registration (APTAP)	7.061 km
Buffer Zones		
Nothing found		
ZAs (Conama Resolution 428 0-2km)		
Nothing found		
ZAs (Conama Resolution 428 0-3km)		
Nothing found		

Figure 8. Example of a report generated by SISLA, with the identification of protected areas inside or close to the property.

Source: Silva et al. (2011b).

Other SISLA modules were developed for internal and exclusive access by technicians from government agencies, such as registration and consultation of the procedural progress per the activity requested; geospatial consultation for generating management reports containing the spatial distribution and the procedural processes; and the visual and individual technical analysis of processes that allows the specialist to issue an opinion for approving or not the process (Figure 9).

In almost 12 years of operation in the state of Mato Grosso do Sul, SISLA'S registered users include professionals from government agencies, private companies, consultants, universities and banks, who use the system to request environmental licenses, as well as to access its geospatial information. Several regulations published by the state government, related to environmental licensing, include analysis carried out by

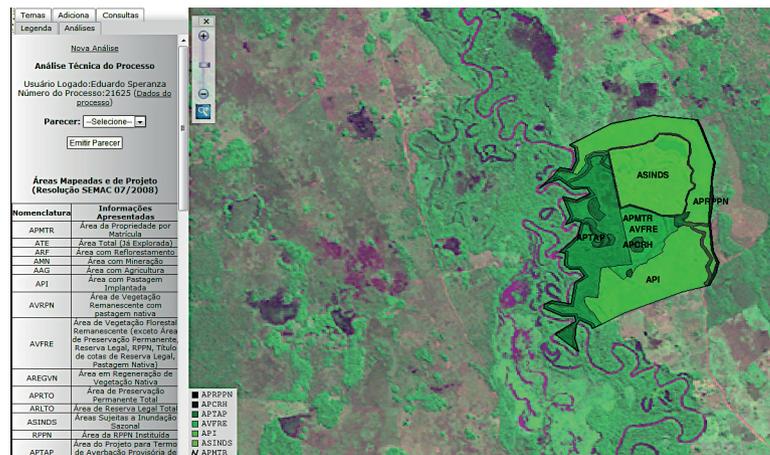


Figure 9. Example of visual and individual technical analysis of the environmental licensing process provided by SISLA.

Source: Silva et al. (2011b).

SISLA as a prerequisite in all phases of the environmental licensing process. Thus, it is possible to affirm that its implementation in the state of Mato Grosso do Sul was successful and can be extended to other municipal, state and federal bodies.

Interactive Geospatial Analysis System for the Legal Amazon (SIAGEO Amazônia)

The Legal Amazon is a Brazilian region established by federal law with the objective of empowering economic planning and for defining public policies and protecting biodiversity in this part of the national territory. This region covers the states of Acre, Amapá, Amazonas, Mato Grosso, Pará, Rondônia, Roraima, Tocantins and part of the state of Maranhão, with a total area of 5,217,423 km², that is, almost 60% of the country's territory.

The occupation of this territory intensified in a disorderly manner from the 1970s onwards, through the implementation of production systems incompatible with the sustainability of the region's natural resources. The ZEE, an instrument of the National Environmental Policy, was then established by the Federal Government in order to achieve sustainable development by making socioeconomic development compatible with environmental protection. It was elaborated based on the diagnosis of the physical, biological, socioeconomic and legal-institutional means and on establishing exploratory scenarios for the proposition of guidelines for each identified territorial unit, including actions aimed at correcting existing harmful environmental impacts. The economic, social, environmental and cultural specificities, the vulnerabilities and potential of each state, resulted in obtaining different guidelines and procedures, in their ZEEs, for planning the occupation and use of their territories (Brasil, 2020).

The project Ecological-Economic Zoning Uniformization of the Legal Amazon and Integration with Agroecological Zoning of the Region (UZEE) was carried out by Embrapa with the objective of integrating the different state ZEEs and providing a global characterization of the Legal Amazon, capable of subsidizing the construction of macro-regional public policies consistently and independently of state boundaries. The leadership of this project was directed by Embrapa Eastern Amazon, with the participation of Embrapa Digital Agriculture, and with the support of the Ministry of the Environment (MMA) and the states covered by the Legal Amazon for the access and data validation used in the construction of the state ZEEs. The project had financial support from the Financier of Studies and Projects (FINEP) of the Ministry of Science, Technology and Innovation (MCTI).

To meet the need for organization, storage and availability of geospatial information of the project as well as the data from the state ZEEs and the respective basic data used to build them, the Interactive Geospatial Analysis System of the Legal Amazon (SIAGEO Amazônia) was developed, as shown in Figure 10.

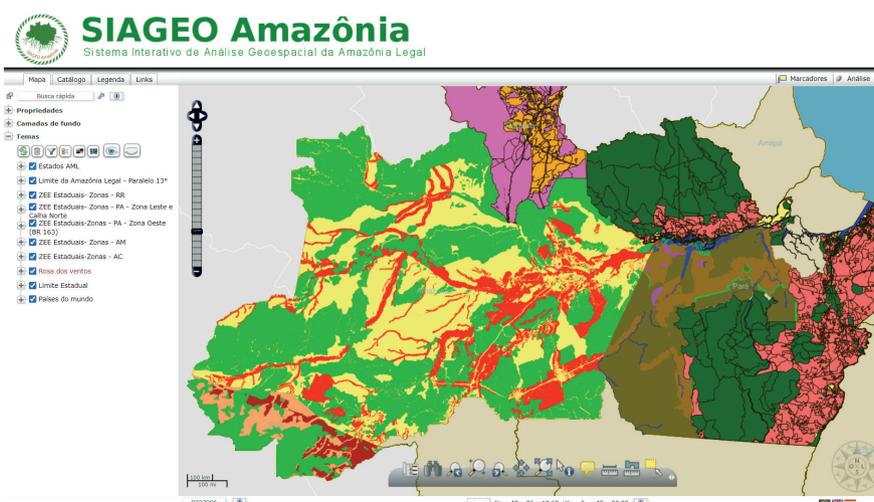


Figure 10. SIAGEO Amazon screen.

Source: Embrapa Agricultural Informatics (2020b).

SIAGEO Amazon⁴ enables users to visualize and obtain interactive georeferenced maps and tabular data through the manipulation of different levels of information according to the user's interest and need. Similarly, it allows the user to perform spatial analysis based on a vector reference data, such as points, lines or polygons, and a set of thematic maps that are structured in WebGIS, in addition to providing access to technical documents and legal frameworks for each zoning initiative.

Currently, the system has a total of approximately seven thousand layers of geospatial data, both in vector and raster format, properly cataloged and organized so they can be viewed directly in the tool, downloaded for user consumption or used as parameters for spatial analysis on regions of interest.

SIAGEO was developed based on free software, and its basic functionalities are derived from the I3Geo software. The system has modules for generating two types of environment reports, which allow characterizing the neighborhood of a region of interest. The first one is the Spatial Analysis Module, which allows a user to send the geospatial data of their area of interest and obtain a neighborhood report regarding a set of themes selected from those already cataloged in the system. The Banking Module, on the other hand, offers a similar approach, but the themes used for the neighborhood analysis are pre-selected and placed in those determined by the banking institutions as relevant for the analysis of project financing.

Final considerations

In recent decades, Brazilian agriculture has experienced intense processes of structural, technological, economic, social and environmental transformations, which have reconfigured the activities of the sector and its territorial dynamics. In this chapter, some initiatives and products of Embrapa Digital Agriculture were presented. They directly or indirectly meet the demands related to the theme of land management in Brazil, in which agriculture undertakes a large role due to its dynamic characteristic and outstanding contribution to the outcome of the national Gross Domestic Product. All mentioned technological solutions, developed using free software, are public and with unrestricted use, guaranteeing their access and use by all of society.

Geotechnologies are essential tools for the generation of data and information that contribute to discussions and official positions of governments in different forums related to strategic management of the national territory, as well as facing crises and decisive questions for the defense and maintenance of national sovereignty.

New scientific challenges arise for the treatment, organization and availability of volumes of geospatial data, produced at increasing speed and quantity as a result of the evolution and emergence of new geotechnologies. Future perspectives indicate that, in the process of digital transformation, geospatial data will be increasingly present in people's daily lives, increasing the demand for geospatial services and solutions to improve production and decision-making processes related to territorial intelligence and the management of landscape dynamics.

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⁴ Available at: www.amazonia.cnptia.embrapa.br

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