RESEARCH PAPER

LANDSCAPE CARTOGRAPHY IN THE MARANHENSE AMAZON: THE CASE OF THE LOWER COURSE OF THE PINDARÉ RIVER BASIN

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ABSTRACT. The landscape cartography assesses the functional, dynamic, structural and morphological aspects of landscapes, regardless of their taxonomic scale. It seeks to use these units to support environmental and territorial planning and management. Thus, the present study sought to apply this line of analysis to the Pindaré River Basin, precisely in its lower course, located in the Brazilian state of Maranhão. The objective was to identify, classify, map and analyze the landscapes of the lower course through the correlation of variables related to geology, relief, soils, land use and land cover providing data to support and promote preservationist and conservationist public policies and actions in the area. The methodology identified four levels of landscape analysis, from morphometric aspects, geoforms and upper units to reaching the final landscape map, using field output, digital elevation models and satellite images to validate information. The procedures allowed to identify the landscape heterogeneity in a unique environment of saturated and periodically flooded soils contrasting with extensive pastures and little native vegetation. As a result, seven first-level landscape units were identified, coming up to fifty-eight sub-units in the final map. The work aims to apply the methodology in an area of the Maranhão State where few studies on landscape cartography have occurred. The target is to comprehend possible relationships between the functional and structural potential of landscapes and their relationship with the current intensity of land use, contributing to physical-territorial planning permeating geoecological sustainability.

KEYWORDS: Landscape Mapping; Geosystems; Amazon Basin; Baixada Maranhense

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INTRODUCTION

Landscape cartography allows the assessment of geosystemic units in the context that they all have an environmental/geoecological, social, economic and cultural functionalities that when overexploited bring environmental problems and irreversible impacts to the natural system. The method and technique seek to enter the geosystemic bias, in which the landscape reflects the relationships between natural (abiotic and biotic), technical-economic, and socio-cultural components. The concept of landscape discussed in this article follows Zonneveld (1995) and Mateo Rodriguez, Silva and Cavalcanti (2013), that is, a complex and open space-time system that originates and evolves through a constant transfer of energy, matter, and information. According to (Littell et al. 2018; Newman et al. 2019), these are complex systems, and the Landscape Cartography is the way to interpret the landscape and comprehend its structure, functioning, dynamics, evolution, and indicators, widely discussed in the works of De Pablo (1988), Mateo Rodriguez, Silva and Cavalcanti (2013) and Cavalcanti (2014). Approaching the landscape as an object of scientific investigation enables to incorporate information that supports environmental diagnoses, even physical-territorial orders, proposing forms of rational use in the face of existing weaknesses and potential. Therefore, the relevance of applying it in the context of a basin. The subject has been widely discussed through the estimation of landscape temporal changes (Cunha et al. 2020), predictive scenarios (Amorim, 2015), landscape heterogeneity and hydrological processes (Gao et al. 2018), assessment of geoecological status (Brugnoli and Salinas Chávez, 2021), geoecological diagnosis (Brugnoli et al. 2022). Several other studies admit the landscape as an operational concept of analysis, and the basin as a territorial unit of study, and both concepts come together when focusing on environmental themes. Systemic analysis based on Society/Nature relationship is essential for its cartography (synthesis, analytical and descriptive) and responds to environmental problems proposing adequate ways to minimize them, and indicate rational ways of land use. Thus, applying such concepts in a degraded area that presents problems and weaknesses is essential to achieve geoecological sustainability.

The Pindaré River Basin comprises thirty-eight municipalities. The present study focusses its lower course, in the so-called Baixada Maranhense, located in a region known for deforestation and landscape fragmentation with wide destruction of native forests, especially ombrophilous with remnants of the Cocais Forest. Especially the Amazon the presented increases in anthropogenic actions on natural environments in the last decades, intensifying processes that replace natural vegetation by other land covers. These interventions had converted extensive and continuous areas covered with forests into agriculture, urban areas, and other covers, causing environmental impacts. In many cases, the lack of planning for these processes threatens water sustainability of basins in the Amazon region (Yesuph & Dagnew 2019; Rocha; de Lima & Adami, 2021).

The lower Pindaré region is an ecologically diverse and complex environment, periodically flooded, and more than 97% of its areas present flat to Smoothly undulating topography, no more than 20% slope. The region presents drainage channels that converge with ponds, lakes and rivers, and intertwine through streams. The meandering and anastomosing drainage channels form a rich hydric and geomorphological structure. According to Costa-Neto (2002), the dynamic is due to the rain seasonality with well- defined dry and rain seasons. The rainy season occurs from January to July over the extensive flat area causing significant floods, due to the little depth of lakes and rivers in the region, thus, water table rises and soils saturate in water. However, during the dry season, the slopes form extensive dry fields and shrubby vegetation, grasses and cyperaceae. Such occurrences and dynamics raised the hypothesis that the flat relief favors this unique seasonality, however, it favors occupation by human beings. Pastures predominate the area replacing the native vegetation, fragmenting the landscape. Facing the landscape functional aspects, this research aims to realize whether these units have been fulfilling their ecological functions, as well as identifying environmental difficulties, using the data collected to propose ways to mitigate weaknesses. The relevant and diversified current data about the Maranhense Amazon present less accuracy and/or incongruity as approaching more local and regional scales of analysis, making it impossible to adapt development/ planning programs to the fragile physical environment. In agreement with Salinas Chávez and Ribeiro (2017) and Brugnolli et al. (2022), landscape cartography according to the methodology proposed here, works to adjust and balance the three geoecological views, geographic, socioeconomic and ecological.

The present work sought to identify, map and analyze the landscape units of the lower course of the Pindaré River Basin (Figure 1), in order to identify the existing correlations between geology, relief, soil, and land use and land cover. The results may contribute to establish the River Basin Committee of the Mearim River - law 9,957 (Maranhão, 2013), which the Pindaré River belongs to, as well as relevant data of a little studied region.

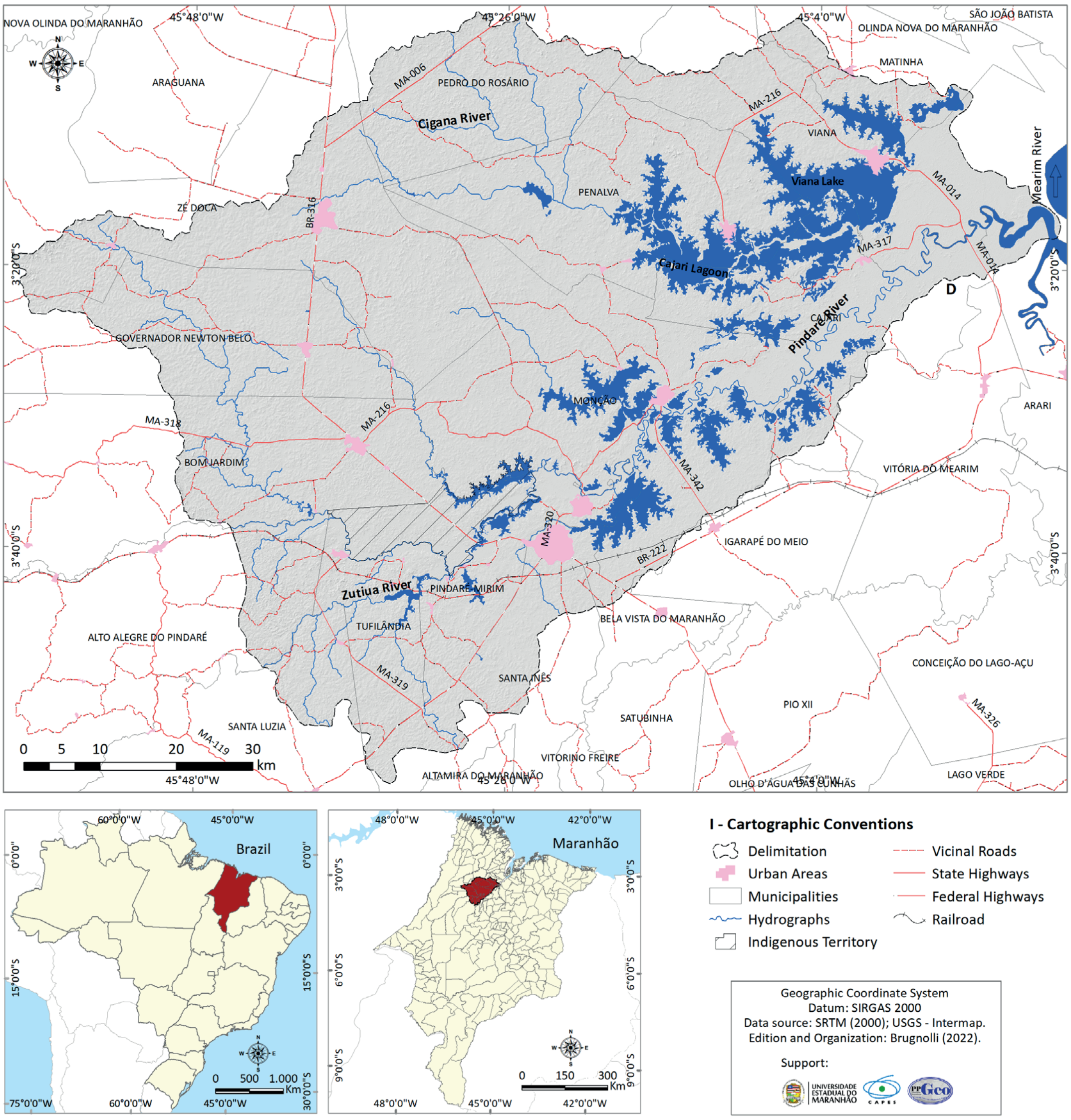

Fig. 1. Location of the lower course of the Pindaré River Basin, Maranhão

METHODOLOGY

The methodology applied here approached two basic steps. The first consists of surveying the landscape components, and the second links to the interactive analysis among them, using basic methodologies of landscape cartography. The procedures start by using the Digital Terrain Model of the Shuttle Radar Topography Mission (DTM/ SRTM), acquired free of charge through the Earth Explorer of the United States Geological Survey. The model went through pre-processing steps to correct noise, spurious pixels, and to fill in existing defaults. The procedures were performed in a Geographic Information System environment, using QGIS Desktop 3.16. In the sequence, we carried out the hypsometric mapping of the study area to identify the elevations and altimetric levels. The same base (DTM/SRTM) was used to generate the slope of the area, using the Brazilian Soil Classification System (Sistema Brasileiro de Classificação de Solos - SIBCS, 2018) to define the slope classes to be compartmentalized: 0.00 to 3.00% - flattened; 3.01 to 8.00% - Smoothly undulating; 8.01 to 20.00% - undulating; 20.01 to 45.00% - strongly undulating. The geology data (morphostratigraphic units) were defined using the base of the Mineral Resources Research Company (Companhia de Pesquisa de Recursos Minerais – CPRM). However, we identified incongruities, and small sand and classification errors, due to its scale. Thus, field works were performed for detailing and support data, as well as the use of DTM/SRTM and satellite images, more precisely the mosaic of images of the QuickMapServices, add-on to QGIS Desktop 3.16. In this matter, the adjustment and the definition and delimitation of polygons (example for the plains) in the area improved and detailed the base with the terrestrial reality. For soils, we used the Ecological-Economic Zoning of Maranhão base. For the adjustment and detailing, the same procedures described in geology were used, such as DTM/SRTM, field work, and mosaic of images to investigate and correct incongruent polygons. Details and corrections that stand out and are necessary for working with landscape cartography. In this first phase, we worked with data from MapBiomas (2020) to classify land use and land cover. The Landsat 8 satellite images allowed to identify mangrove classes, flooded field and swampy area, grassland formation, savanna formation, forest formation, pasture, apicum, other temporary crops, urbanized, area and water. Afterwards, an interactive analysis was carried out at four levels between the landscape components (Figure 2) to identify, classify, and map the landscape units of the lower course of the Pindaré River Basin. The analysis and cartography comprise methodologies in agreement with Salinas Chávez and Ribeiro (2017) and Brugnolli and Salinas Chávez (2021), supported by authors such as Mateo, Silva and Cavalcanti (2013) and Cavalcanti (2014). Comprehending that the units are physical-territorial complexes with relatively homogeneous characteristics with their own geoecological and anthropic functions, allow them to be delimited under the precepts of a geosystemic perspective.

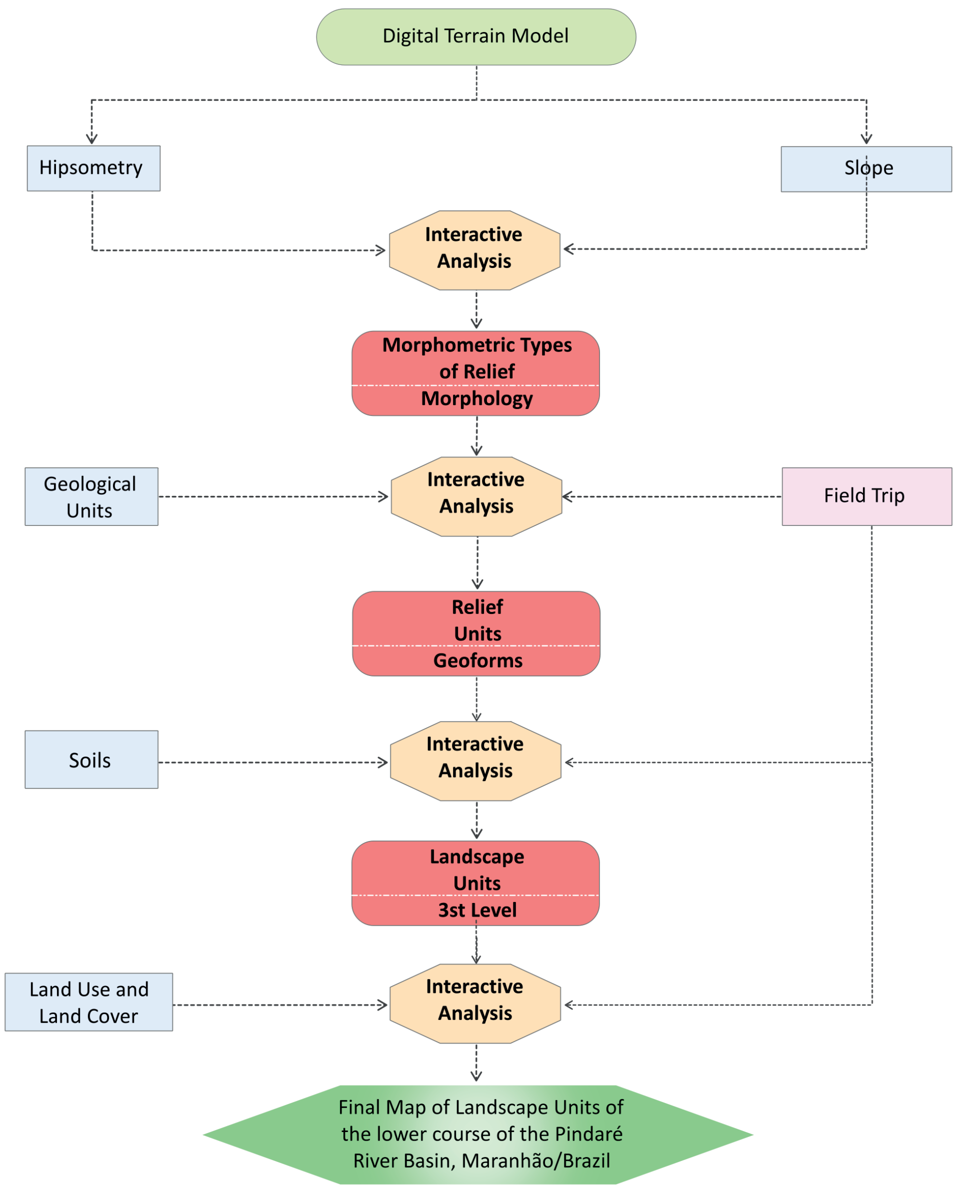

Fig. 2. Methodological flowchart applied to the Pindaré River Basin, Maranhão

We highlight that the levels are the synthesis of integrated variables, and the tabulation results may compartmentalize the study area. Thus, the first compartmentalization occurs through the integration between hypsometry and slope, both derived from the DTM/SRTM. The result of this first level of landscape units are the morphometric aspects of relief/morphology. Subsequently, the result of the first phase and the geological aspects (geological units) are approached, with a field trip to verify the acquired and generated information. In the field trip, we used the Global Positioning System - Garmin eTrex Portable GPS, photographic cameras, and the DJI Mavic Drone, for vertical and oblique photographs of the landscape, leading to the second level of landscape units, called geoforms. The geoforms correlate with soils, reaching the third level and, then, with land use and land cover, ending the fourth and last level, that is, the final map of landscape units of the PRB lower course. The final map allows to use such units for environmental and territorial purposes of management and planning, as they all present unique geoecological and anthropic aspects. The units present their own functionalities, structures, dynamics and evolutions favoring the comprehension of the environmental use-exploitation- services.

It is important to note that the interactive analyses that take landscapes from level to level, relied on automated interpolation via GIS, in a multicriterial assessment and clusterization, in which clustering is performed with a view to finding homogeneous units. From this classification, the empirical role of researchers and knowledge about the study area enters the discussion as a way to validate the data obtained automatically and improve the final quality of the products generated.

ENVIRONMENTAL CHARACTERIZATION OF THE LOWER COURSE OF THE PINDARÉ RIVER BASIN

The Baixada Maranhense presents a unique landscape, seasonally influenced by the water table and precipitation (rain cycle) variation. It is characterized by its large and extensive lake environments and paths/channels that intertwine until reaching the water sources. As the region is adjusted to the general base level, there are areas under the influence of tides through streams (igarapés) making the salinization of the waters a significant negative factor. In this complex hydric and geomorphological structure, the soil partially saturated in water contrasts with areas of pasture, rice plantations, native vegetation, urban areas, and some temporary crops (Figure 3).

In the wetlands predominate recent geological structures with alluvial and fluvial-lacustrine deposits dated from the Quaternary period, recent within the Brazilian geological structure. The structures present large deposits of sand, silicon, clay and gravel. According to Rodrigues et al. (2014), the sediments may be linked to the fluvial course (alluvial) and/or lake environments (fluvial-lacustrine) that were transported and deposited over the last 10 thousand years. In the areas close to the water sources, we identify estuaries and anastomosing channels that flow to the Mearim River, which runs 40 km to the São Marcos Bay, north of Maranhão State. The fact explains the presence of mangroves, the so-called Igapó Forest, recent and water-saturated soils, such as the fluvic neosol and the thiomorphic gleysols, as well as the apparent salinization of the main river and the tributaries close to the mouth of the Pindaré River, as pointed by Machado and Pinheiro (2016) and Almeida et al. (2020). The salinization or marine intrusion occurs altering the riparian zones. The intrusion is due to anthropic interferences, the reduction of riparian vegetation, conversion of native vegetation to pastures and rice crops. Facts that contribute to the silting of upstream areas, and increase of sediments carried to the meanders, changing the local base level and modifying the upstream water structure. The proximity to the general base level contribute to the intrusion and interference in the region, as the northern region of Maranhão is strongly influenced by tide variation. During the high tide, the river waters rise causing impacts on the hydrodynamics and local biodiversity. The native vegetation proves to be resistant in specific areas, however, the entrance of pasture advances and devastate the banks of water sources. Livestock activities are not suitable for the region due to several limitations, such as the soils (haplic, melanic and thiomorphic gleisols, and fluvic neosols) and relief, located in floodplains and plains. The floodable areas contrast with river terraces and Smoothly undulating to undulating surfaces linked to old rocks, such as the Itapecuru Formation, linked to claystones, siltstones and shales interspersed with sandstones deposited in various environments. The deposition presents predominantly continental influence, however, indications of marine transgressions (CPRM, 2013) are present, as well. Deep and well-developed soils predominate the areas, such as plintosols and argisols, common in hot and humid equatorial zones. According to EMBRAPA (2018), these soils exhibit poor drainage, and excess of humidity. Even tough, the area shows agricultural potential, due to its location on flat to Smoothly undulating reliefs. Small patches of native vegetation remain in the area, mainly dense and open ombrophilous forests. The Baixada Maranhense area is predominantly used by pastures, some left fallow, and others for cattle and buffalo. The buffalo livestock has caused a series of environmental problems, due to the weight of the animal. They trample the soil causing the silting of springs and flat, degraded, floodable and fragile slopes. Thus, the Public Ministry of Maranhão sued some municipalities for their lack of control facing the activity, since the region is an Environmental Protection Area - EPA (Área de Proteção Ambiental - APA), according to state decree nº 11.900 (Maranhão, 1991).

We highlight that the region is part of the Golfão Maranhense, in which the occupational process has reached drastic levels. The region has been consolidated as one of those located in the arc of deforestation, due to the anthropic actions and significant disappearance of native vegetation. Anthropic actions are identified even in swamp lands with rice planting in the river plains. In addition, the region presents humid tropical climate with a dry season (July to December) and a rainy season (January to June), favoring the seasonality of floods and droughts in the Baixada Maranhense. The region comprises diverse geosystems, complex and distinct typologies, validating the present proposal of identifying, classifying and mapping the landscape physical-geographical units, analyzing them under the environmental study.

LANDSCAPE UNITS OF THE LOWER COURSE OF THE PINDARÉ RIVER BASIN

The research approached landscape cartography to comprehend the correlations between the natural and social components of the lower course of the Pindaré River Basin, a complex area of Maranhão State. The purpose is to define relatively homogeneous units to facilitate and support the planning and management process of these units. Studying them is a fundamental step towards success in actions and decision-making, as it allows establishing an adequacy between current uses and the support capacity and balanced functioning of the units (Figure 4 and Table 1).

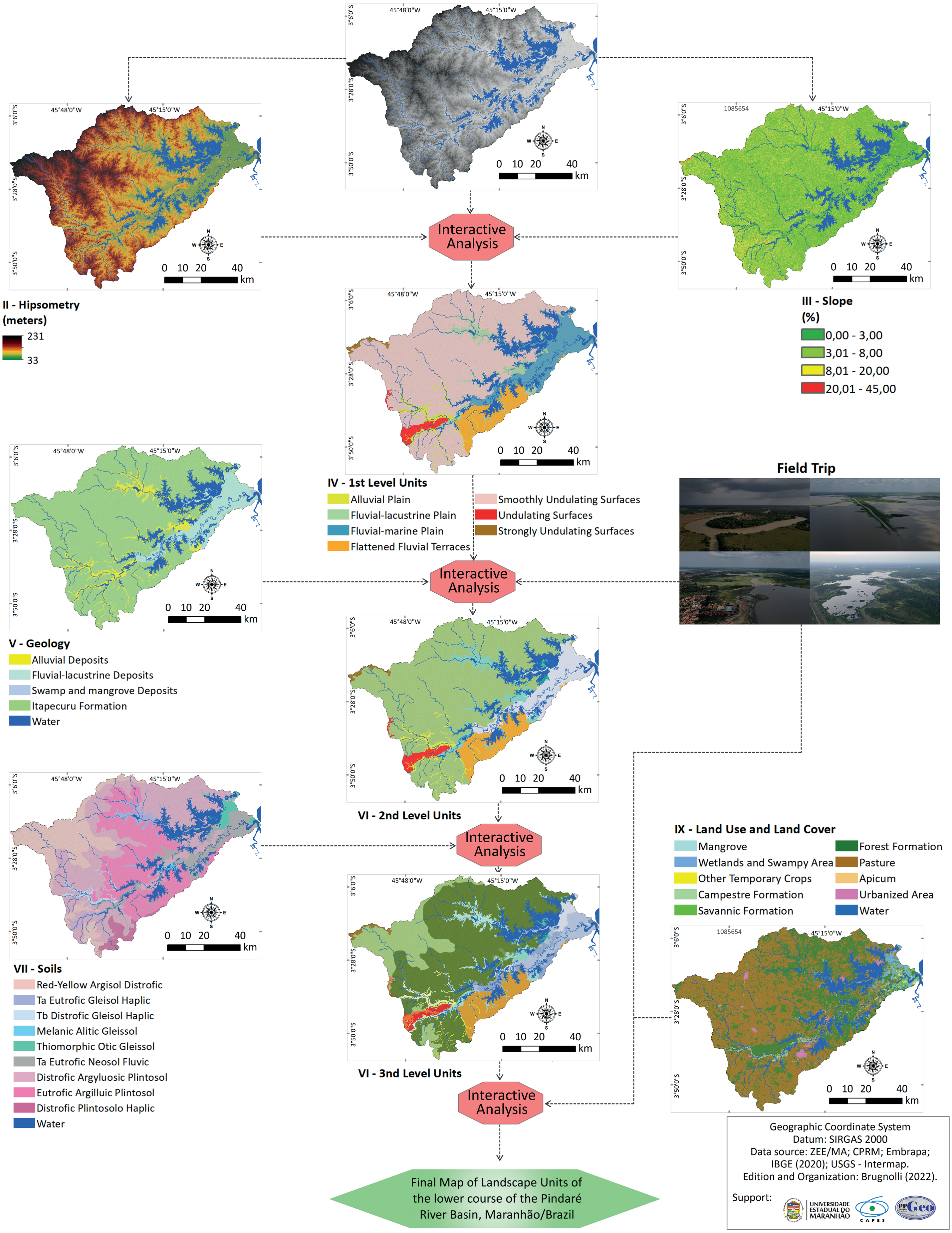

Fig. 3. Physical and anthropic components of the lower course of the PRB, Maranhão

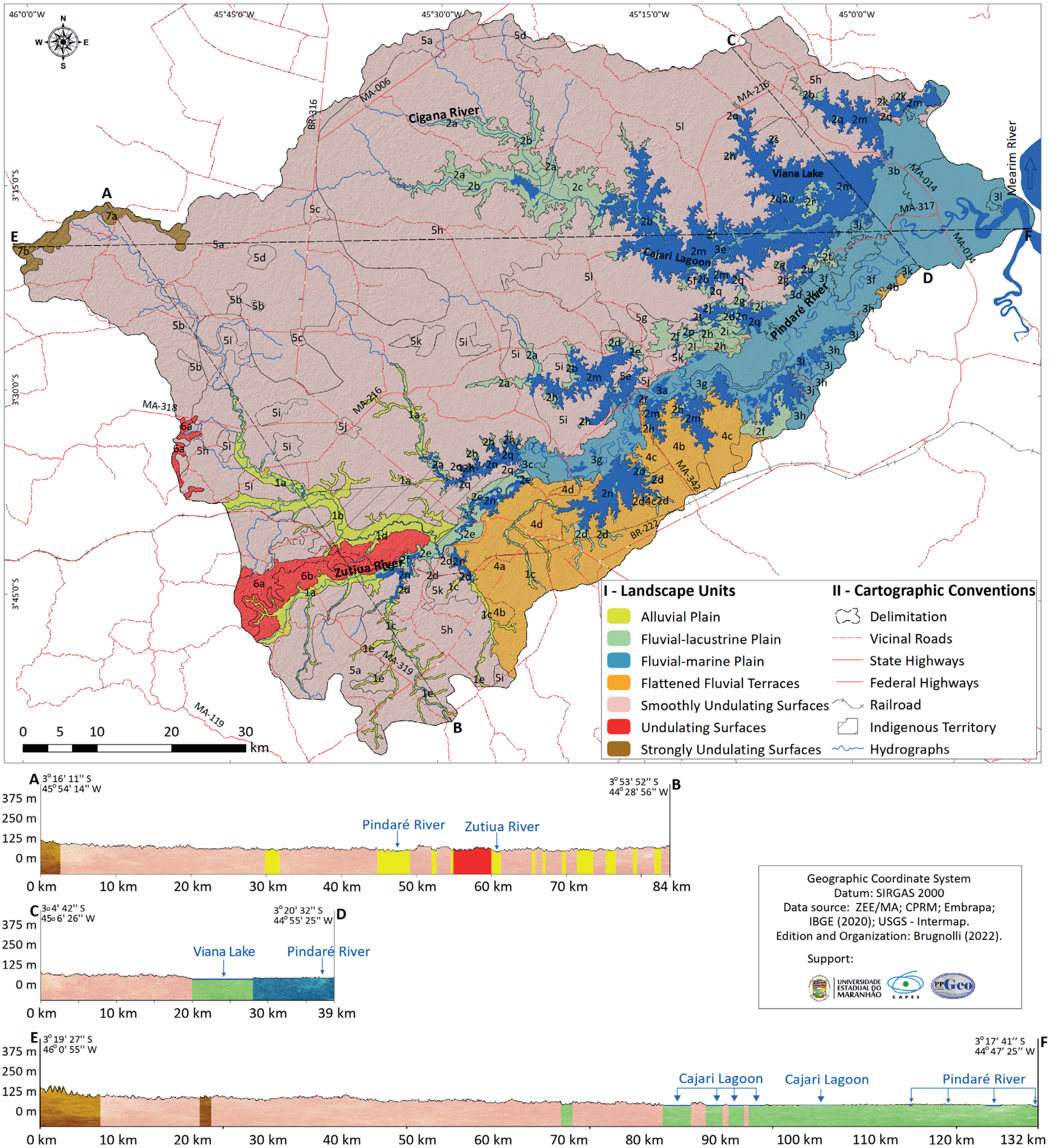

Fig. 4. Landscape Units of the lower course of the Pindaré River Basin, Maranhão

The description of the units follows a hierarchy linked to the relief. According to Serrano (2012), Hernandez et al. (2017), Khoroshev (2019) and Comerlato, Lamour and Silveira (2020), the relief is the essential component in environmental systems as the agent that redistributes the flows of matter and energy in the system. Thus, the relief acts significantly in the distinction and typology of landscape units.

LU1 - Alluvial Plain – The unit associated with water resources, typical of valley bottoms, of receiving property with sediment accumulations. The rocks are predominantly formed by recent sand, silt and gravel (alluvial) deposits, dating from the Quaternary. They cover a total of 195.82 km^2, that is, 2.82% of the study area along five sub-units. The soils vary from gleisol in the areas close to springs, neosols, especially fluvic, and plinthsols. The flattened relief does not exceed 3.00%, and they are periodically flooded, presenting predominance of grassland and forest vegetation in the riparian zones. However, several areas are degraded with pastures and remnants of vegetation forest, and some pastures have already reached the banks of water sources. The plains are not associated with lacustrine environments. The area presents restricted plains at the beginning of the low course, as well as a single extensive plain at the confluence of the Zutiua River with the Pindaré River (Figure 5).

These sub-units present major land use limitations, since they are fragile areas from the pedological, geomorphological, and geological view. The large areas are periodically flooded by the water source overflows, and as permanent preservation areas, restrictions are imposed. The water resources are silted with large and extensive sandbanks, and the riparian zones show wide open gaps with pastures. Therefore, the recommendation

Table 1. Description of the Landscape Units of the Pindaré River Basin

Landscape Units							
Units		Coverage Areas (km²) (%)		Characteristic of the Unit at Pindaré River Basin			
				Geology	Slope	Soils	Land Use and Land Cover
Alluvial Plain	1a	81,00	1,17	Alluvial Deposits	0,00 a 3,00 %	Gleisols	Pasture with vestiges of forest vegetation
	1b	56,78	0,82	Alluvial Deposits	0,00 a 3,00 %	Gleisols	Grassland and forest vegetation in riparian zones
	1c	24,32	0,35	Alluvial Deposits	0,00 a 3,00 %	Neosols	Pasture with vestiges of forest vegetation
	1d	14,39	0,21	Alluvial Deposits	0,00 a 3,00 %	Neosols	Grassland and forest vegetation in riparian zones
	1e	19,33	0,28	Alluvial Deposits	0,00 a 3,00 %	Plintosols	Pasture with vestiges of forest vegetation
Fluvial-lacustrine Plain	2a	37,35	0,54	Alluvial Deposits	0,00 a 3,00 %	Gleisols	Pasture with vestiges of forest vegetation
	2b	106,54	1,54	Alluvial Deposits	0,00 a 3,00 %	Gleisols	Wetland with dense forest vegetation
	2c	37,20	0,54	Alluvial Deposits	0,00 a 3,00 %	Gleisols	Pastures in the middle of the lagoons with remnants of forest vegetation
	2d	19,62	0,28	Alluvial Deposits	0,00 a 3,00 %	Neosols	Pasture with vestiges of forest vegetation
	2e	37,38	0,54	Alluvial Deposits	0,00 a 3,00 %	Neosols	Grassland and forest vegetation in riparian zones
	2f	37,83	0,55	Alluvial Deposits	0,00 a 3,00 %	Neosols	Open Forest Vegetation
	2g	5,72	0,08	Alluvial Deposits	0,00 a 3,00 %	Neosols	Wetland with dense forest vegetation
	2h	22,38	0,32	Alluvial Deposits	0,00 a 3,00 %	Plintosols	Pasture with vestiges of forest vegetation
	2i	13,18	0,19	Alluvial Deposits	0,00 a 3,00 %	Plintosols	Dense forest vegetation
	2j	1,37	0,02	Alluvial Deposits	0,00 a 3,00 %	Plintosols	Grassland and forest vegetation in riparian zones
	2k	1,34	0,02	Alluvial Deposits	0,00 a 3,00 %	Plintosols	Wetland with dense forest vegetation
	2l	5,79	0,08	Alluvial Deposits	0,00 a 3,00 %	Plintosols	Open Forest Vegetation
	2m	430,93	6,21	Fluvial-lacustrine deposits	0,00 a 3,00 %	Gleisols	Lakes and Lagoons
	2n	111,85	1,61	Fluvial-lacustrine deposits	0,00 a 3,00 %	Neosols	Lakes and Lagoons
	2o	0,61	0,01	Fluvial-lacustrine deposits	0,00 a 3,00 %	Neosols	Dense forest vegetation
	2p	0,91	0,01	Fluvial-lacustrine deposits	0,00 a 3,00 %	Neosols	Dense forest vegetation
	2q	2,58	0,04	Fluvial-lacustrine deposits	0,00 a 3,00 %	Plintosols	Dense forest vegetation
	2r	10,49	0,15	Fluvial-lacustrine deposits	0,00 a 3,00 %	Plintosols	Pasture with vestiges of forest vegetation
	2s	0,57	0,01	Fluvial-lacustrine deposits	0,00 a 3,00 %	Plintosols	Lakes and Lagoons
	2t	5,55	0,08	Itapecuru Formation	0,00 a 3,00 %	Neosols	Pasture with vestiges of forest vegetation
	2u	5,31	0,08	Itapecuru Formation	0,00 a 3,00 %	Plintosols	Pasture with vestiges of forest vegetation
Fluvial-marine Plain	3a	24,36	0,35	Fluvial-lacustrine deposits	0,00 a 3,00 %	Gleisols	Grassland and forest vegetation in riparian zones
	3b	92,06	1,33	Fluvial-lacustrine deposits	0,00 a 3,00 %	Gleisols	Wetland area with grassland and forest vegetation
	3c	11,42	0,16	Fluvial-lacustrine deposits	0,00 a 3,00 %	Neosols	Grassland and forest vegetation in riparian zones
	3d	2,35	0,03	Fluvial-lacustrine deposits	0,00 a 3,00 %	Neosols	Pasture with vestiges of forest vegetation
	3e	1,69	0,02	Fluvial-lacustrine deposits	0,00 a 3,00 %	Neosols	Dense forest vegetation

Fluvial-marine Plain	3f	413,44	5,96	Fluvial-lacustrine deposits	0,00 a 3,00 %	Neosols	Wetland area with grassland and forest vegetation, with some temporary crops, mainly rice plantations.
	3g	89,32	1,29	Fluvial-lacustrine deposits	0,00 a 3,00 %	Plintosols	Grassland and forest vegetation in riparian zones
	3h	77,00	1,11	Fluvial-lacustrine deposits	0,00 a 3,00 %	Plintosols	Pasture with vestiges of forest vegetation
	3i	0,09	0,00	Fluvial-lacustrine deposits	0,00 a 3,00 %	Plintosols	Dense forest vegetation
	3j	25,59	0,37	Fluvial-lacustrine deposits	0,00 a 3,00 %	Plintosols	Open Forest Vegetation
	3k	3,36	0,05	Fluvial-lacustrine deposits	0,00 a 3,00 %	Plintosols	Mixed Vegetation
	3l	7,74	0,11	Swamp and mangrove deposits	0,00 a 3,00 %	Gleisols	Swamps and mangroves
Flattened Fluvial Terraces	4a	308,44	4,45	Itapecuru Formation	0,00 a 3,00 %	Plintosols	Pasture with vestiges of forest vegetation
	4b	53,01	0,76	Itapecuru Formation	0,00 a 3,00 %	Plintosols	Open Forest Vegetation
	4c	63,63	0,92	Itapecuru Formation	0,00 a 3,00 %	Plintosols	Dense forest vegetation
	4d	27,22	0,39	Itapecuru Formation	0,00 a 3,00 %	Plintosols	Urban Area
Smoothly Undulating Surfaces	5a	984,48	14,19	Itapecuru Formation	3,01 a 8,00 %	Argisols	Pasture with vestiges of forest vegetation
	5b	25,87	0,37	Itapecuru Formation	3,01 a 8,00 %	Argisols	Dense forest vegetation
	5c	14,79	0,21	Itapecuru Formation	3,01 a 8,00 %	Argisols	Urban Area
	5d	28,11	0,41	Itapecuru Formation	3,01 a 8,00 %	Argisols	Open Forest Vegetation
	5e	1,25	0,02	Itapecuru Formation	3,01 a 8,00 %	Gleisols	Pasture with vestiges of forest vegetation
	5f	2,17	0,03	Itapecuru Formation	3,01 a 8,00 %	Gleisols	Open Forest Vegetation
	5g	29,68	0,43	Itapecuru Formation	3,01 a 8,00 %	Neosols	Pasture with vestiges of forest vegetation
	5h	2302,30	33,18	Itapecuru Formation	3,01 a 8,00 %	Plintosols	Pasture with vestiges of forest vegetation
	5i	176,03	2,54	Itapecuru Formation	3,01 a 8,00 %	Plintosols	Open Forest Vegetation
	5j	10,75	0,15	Itapecuru Formation	3,01 a 8,00 %	Plintosols	Urban Area
	5k	37,89	0,55	Itapecuru Formation	3,01 a 8,00 %	Plintosols	Dense forest vegetation
	5l	863,02	12,44	Itapecuru Formation	3,01 a 8,00 %	Plintosols	Pastures with large fragments of dense forest vegetation
Undulating Surfaces	6a	50,36	0,73	Itapecuru Formation	8,01 a 20,00%	Argisols	Pasture with vestiges of forest vegetation
	6b	81,32	1,17	Itapecuru Formation	8,01 a 20,00%	Plintosols	Pasture with vestiges of forest vegetation
Strongly Undulating Surfaces	7a	26,93	0,39	Itapecuru Formation	20,01 a 45,00%	Argisols	Pasture with vestiges of forest vegetation
	7b	12,60	0,18	Itapecuru Formation	20,01 a 45,00%	Argisols	Open Forest Vegetation

is to recover the areas with native vegetation, and to intensify the restriction on the entry of cattle on the banks of water sources. Actions that may bring environmental valuation to the region, and, as the "the gateway" to the Baixada of Maranhense, the silting of downstream areas (fluvial-lacustrine and fluvial-marine environments) may be reduced, as well.

LU2 - Fluvial-lacustrine Plain – Unit associated with the bottom of valleys, lakes, ponds, and impoundments of the Baixada Maranhense, as well as the entire plain related to these water bodies. It is a depositional environment characterized by an extremely flat relief and low altimetry amplitude. The extensive areas are periodically flooded by the regular rains that occur from January to July. Due to the lacustrine environments, the substrate rocks are mostly fluvial-lagoon deposits, a recent formation dating from the Quaternary and a result of intense sedimentation processes (sand, silt and gravel) of lagoon and fluvial environments. The soils are diverse, however, all clay-bounded and rich in organic matter. The units encompass 894.51 km^2 or 12.89%, and are distributed over twenty-one subunits. The number of sub-units is explained by the rich geodiversity, varied soils, rock formations, and different forms of land use and land cover. The extensive flat plain relief differs from the fluvial plains, linked to lakes, lagoons and islands (Figure 6). On the islands, it occurs the Itapecuru formation, a distinct rock formation where pasture with remnants of forest vegetation predominate.

Extensive wetlands with dense and open forest vegetation (ombrophilous forest) cover the unit, however, the presence of pastures is a fact, impacting the quantity and quality of water sources. We highlight that on the banks of the units, urban areas of the Baixada Maranhense, such as the cities of Viana, Monção, Cajari and Penalva, are

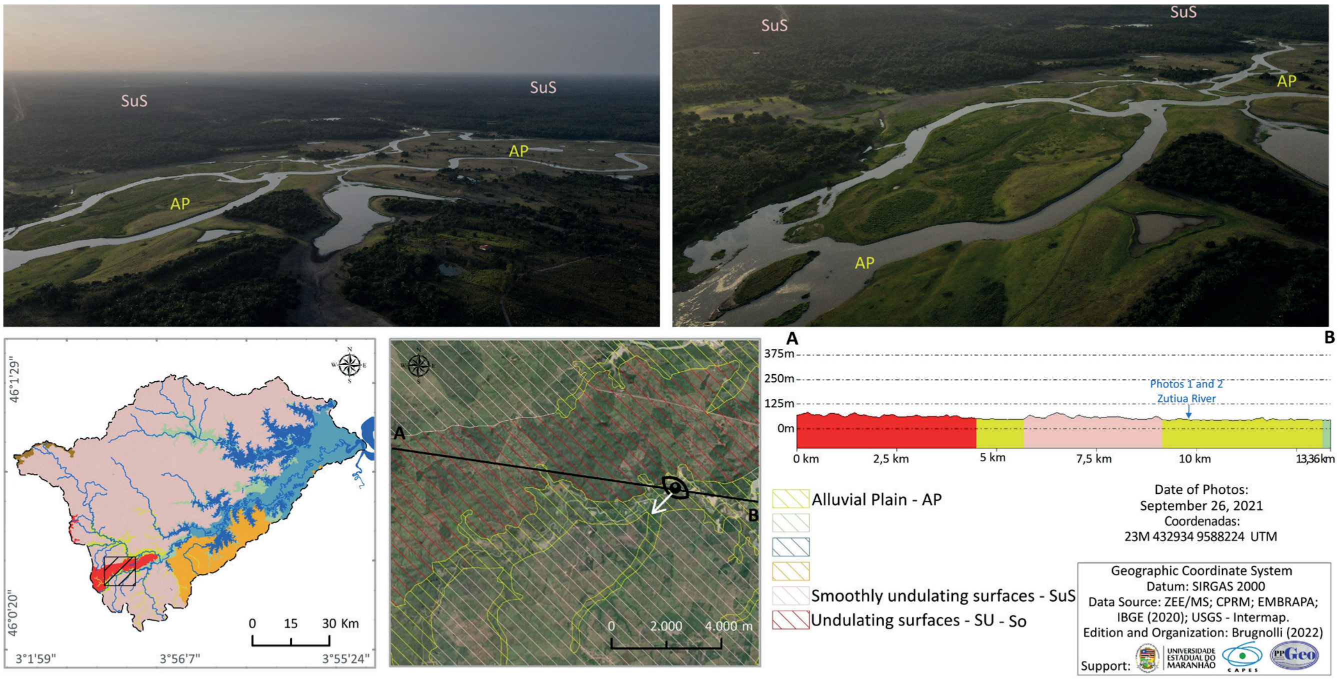

Fig. 5. River Plain near the confluence of the Zutiua River in the Pindaré River

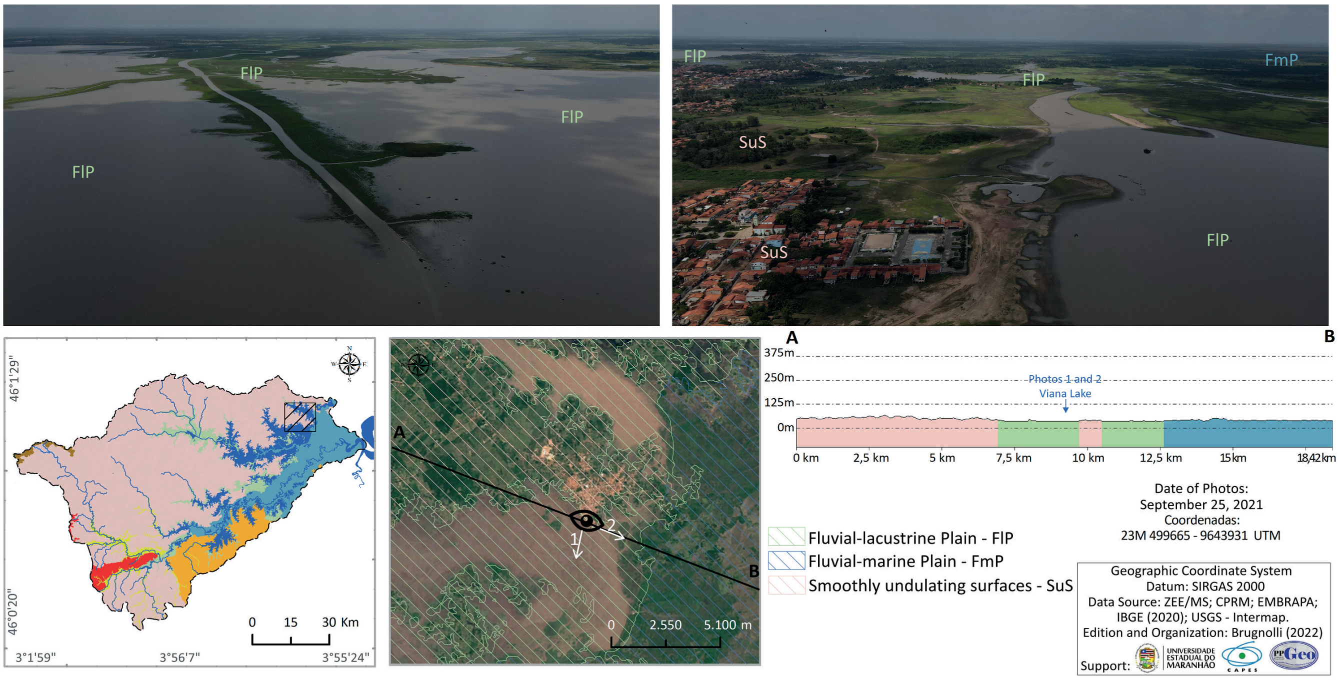

Fig. 6. Fluvial-lacustrine Plain characterized by lagoons, lakes, and islands

affected by the seasonality caused by the floods in the region. The limitations of these sub-units are mainly linked to the saturated soil, and their margins demand protection and preservation. However, the Forest Code (Brasil, 2012), which is responsible to safeguard them, however, it is not applied or supervised. The banks of the lakes have been replaced by pastures as urban areas advance towards them and large part of the population lives from fishing. In addition, the urban areas suffer from recurring floods, causing annual losses for residents. Thus, another issue emerges as the municipalities do not have a municipal sanitation policy, making the ponds dumping sites of solid waste and their waters lose qualitative levels. In this way, it is recommended the restoration of the environmental value of such units by recovering the margins of the lagoons, and retreating the advance of pastures over the wetlands.

LU3 – Fluvial-marine Plain - The unit is linked to the interactions of fluvial and marine processes with coastal sedimentary deposits, swamps, and mangroves with recent colluvium and alluvium (Quaternary) adjusted to the general base level. It presents flat topography, reaching no more than 3%. The extensive plain covers the entire lower course of the Pindaré River, linked to anastomosing and meandering channels that intertwine and interconnect with the fluvial-lacustrine lakes of the unit. The gleysol, neosol, and plinthosol soils present water saturation and floods occur periodically. Therefore, the vegetation that covers the soil offers protection to it due to great amount of natural vegetation, grassland and dense open forest. The ombrophilous vegetation makes the riparian zone the most preserved in the Baixada Maranhense, despite presenting extensive pastures. Salinization occurs in the area affecting the local residents who depend on fishing in the Pindaré River and its tributaries. The LU3 presents 12 sub-units that together cover 748.40 km^2 or 10.79% of the total lower course. An intensive geodiversity occurs in the area with swamps and mangroves (hydrophilic floodplain fields) close to the Pindaré River. Rice is the temporary crop present close to the river mouth, due to the humidity and periodically flooded area. However, it brings environmental damage, such as the construction of drains diverting water runoff, transforming and fragmenting the landscape, as well as over consumption of water available. The sub-units present significant limitations and weaknesses, from the rocky substrate formed by unconsolidated and recent sediments to fragile soils and areas with legal restrictions. Moreover, they present preserved areas, so the recommendation is to maintain the native vegetation with profound restrictions on the advancement of pastures. However, pastures have been identified in the region. In areas where the landscape has already been altered due to crops and/or pastures, a more adequate management may be applied to reduce the construction of drains for crops, and to preserve of the streams that supply the region and regulate the water level of rivers.

LU4 – Flattened fluvial terraces - The unit covers a total of 452.31 km² or just 6.52% of the Baixada Maranhense, and it is represented over four units predominantly formed by the Itapecuru Formation and plinthosols. The terraces occupy higher levels than the plains, showing the periods of evolution. Morphologically, they present flattened levels, lower than 3%, though, not affected by the flood of rivers. The sub-units are located in the southeastern section of the lower course of the Pindaré River, and according to Christofoletti (1980), characterized by the abandonment of the floodplain due to climatic oscillations, mass movements, tectonics, and change in the regime and hydraulic potential of the river. They characterize old units that went through long transformation and sedimentation processes, which left it at higher altimetric levels. It is a watershed between the lower course of the Pindaré and Mearim Rivers that favors occupation, as they are not affected by floods. Pastures predominate the area, and some subunits present open forest vegetation, others present dense vegetation. One unit presents urban area, which corresponds to the municipality of Santa Inês with 77,282 inhabitants, and the highest population in the lower course, according to the Brazilian Institute of Geography and Statistics (Instituto Brasileiro de Geografia e Estatística - IBGE - 2010). The areas present few limitations since their rocks, soils, and relief comprise the current pastures. However, the riparian zones are degraded, many open clearings and pastures entering the water sources, and even the margins of the lakes of the fluvial-lacustrine unit. Thus, we recommend to alter and recompose such areas, but there is no need to change pastures that are out of the Permanent Preservation Areas (PPA) as long as they present land management.

LU5 – Smoothly undulating surfaces - It covers the largest area of the lower course, 4476.33 km² or 64.51% of the total, characterizing the Baixada Maranhense region. Although it presents several sub-units, due to the local geodiversity the topography is Smoothly undulating, below 8% declivity, and the relief linked to an old geological formation, the Itapecuru. They present sandstone, siltstone and shale terrains, subjected to erosional development. The twelve subunits differ by soils (argisols, gleysols, neosols and plinthosols), land use and land cover, displaying extensive degraded areas, pastures that advance to the PPAs, and spaced patches of open forest vegetation. About 70% of the unit present pastures with few remnants of forest vegetation, the rest is divided into urban areas and dense, and open forest vegetation. Pastures predominate the Baixada Maranhense region, part of them in fallow and others with cattle and buffaloes. We highlight two major exceptions, as the dense ombrophilous forests to the north and northwest of the lower course, and a subunit in the central part of the study area which is located in the Pindaré River Indigenous Land. According to satellite images and by the definition of landscape units, this subunit (Indigenous Land) presents the highest density of forest vegetation in the entire Baixada Maranhense. In addition, other typical regional vegetations occur, such as the babassu, characteristic of an ecotone related to the Cocais Forest. Facts that reinforce the relevance exerted by the Indigenous Land. However, the edges of the area present deforestation and the advance of pastures already. Although being suitable for exploration due to its flattened relief, it presents serious environmental problems. Thus, we recommend that the exploration respect the productive potential of the unit. The current functions may proceed as long as conservation practices are taken, and native vegetation preserved.

LU6 – Undulating Surfaces - The unit is located in small territorial portions to the west of the lower course of the Pindaré River Basin. It is a transition area between the medium course (undulating relief) and the lower course, where, according to the Geological Survey of Brazil -CPRM (2013), several geological faults occur, especially directional waste. The sub-units present ancient geological formation, such as the Itapecuru, superimposed by argisols and plinthosols. Subjected to erosional development, the undulating relief of the units reaches 8.01% to 20.00% slope, and pastures predominate the land use with remnants of forest vegetation. The open forest vegetation characterizes the degradation and fragmentation of the unit, covering 131.67 km² or 1.90% of the lower course.

LU7 – Strongly undulating surfaces - The unit is located in the northwest of the lower course of the Pindaré River Basin in areas of watersheds, where high altimetric levels begin. The area characterizes the beginning of the middle course of the PRB with tabular plateaus, and the watershed of the Turiaçu River (to the north). The sub-units face significant deforestation process with pastures covering the region with ombrophilous vegetation. Few remnants of dense forest vegetation remain. The soils are predominantly formed by argisols, which are characteristic of high regions as watersheds, and its geology encompasses the Itapecuru Formation. Despite the significant differences, especially in relief, they cover small territorial portions (39.53 km² or 0.57%), and the delimitation and distinction from the others proved to be necessary due to the strongly undulating topography with slopes reaching up to 45%. Assessing the Pindaré River Basin and its lower course, named Baixada Maranhense, requires entering and researching an area that has been little studied in its environmental context. As in other regions of Maranhão, the researches related to environmental issues and landscape cartography are still scarce. The methodology used in here is not widely applied regionally, making this study relevant from a conceptual, methodological, and application view.

DISCUSSION

The lower course of the Pindaré River Basin presents significant damages. Thus, the resilient capacity of this environmental system may be affected unless urgent measures are taken. We highlight that regardless of the fragile soils, the geoecological stability is present in places with dense ombrophilous forests, wetlands with grassland and/or forest vegetation, lakes, swamps and mangroves, riparian zones with grassland and forest vegetation. These areas correspond to 22% of the total area and free of land use conflicts. Therefore, it is essential to prioritize the vegetation maintenance and to inspect river courses in order to monitor the local water dynamics and surface waters in quantitative and qualitative terms. In medium and long term, the lack of protection and inspection may lead to the domain of pastures all over the region, fragmenting the landscape, affecting surface waters, as well as the entire geoecological stability. The geoecological instability is a concern for those areas that present pastures with few remnants of forest vegetation. According to García-Rivero et al. (2019) and Brugnolli et al. (2022), landscapes undergo significant changes in spatial and functional structure in unstable areas, and may not fulfill their functions and services properly. The flattened relief favors the establishment of pastures in the unstable areas, despite the fragile soils. The intensive land use overlaps the functional capacity of landscapes. These locations cover 60% of the low course of the Pindaré River Basin. The scenario becomes obscure and critical in medium and long-term, generating serious and numerous ecological/environmental, economic and social damages. Similar facts were found in the work of Rocha; de Lima; Adami (2021). Thus, the area demands urgent mitigation measures to restore the geoecological value.

According to Pinton and Cunha (2014), García-Rivero et al. (2019), and Brugnolli and Salinas Chávez (2021), the gradual loss of geoecological functions leads to a high level of instability. The internal relationships between landscape components lose strength, translating into the decrease of productive potential and biological productivity, and the development of intense soil degradation processes and water resources. We highlight that the whole Baixada Maranhense region - the territorial portion in the lower course of the Pindaré River Basin - is defined as an area for preservation with "very high" and "extremely high" priority indices by the Brazilian Institute of Geography and Statistics (IBGE - Instituto Brasileiro de Geografia e Estatística) and the Institute of Socioeconomic and Cartographic Studies of Maranhão (IMESC - Instituto Maranhense de Estudos Socioeconômicos e Cartográficos). Yet, 35% of the lower course of the PRB is located in an Environmental Protection Area - EPA (APA -Área de Proteção Ambiental) in agreement with the National System of Units of Conservation (SNUC - Sistema Nacional de Unidades de Conservação). However, the reality is devoid of social, economic and, environmental preservation and conservation strategies. According to the National System of Units of Conservation (SNUC - BRASIL, 2000), the definition of an EPA is an extensive area with a certain degree of human occupation, endowed with abiotic, biotic, aesthetic or cultural attributes, especially important for the quality of life and well-being of populations. The paramount target is to protect biological diversity, discipline the occupation process, and ensure the sustainability of its natural resources.

Therefore, despite having and allowing human occupation, the impacts on the landscape affect the biological communities and the physical and social components of the area. The Baixada Maranhense region has been seriously impacted, unlinking the basic EPA premise, which is the sustainable use.

CONCLUSIONS

The theories and methods related to landscape cartography and the definition of its units are linked to the integrated analysis and comprehension of the basin as a manifestation of geosystems. Each geosystem with its own structure, dynamics, functioning, and evolution. Studying the Baixada Maranhense through environmental indicators allowed us to apply the methodology described here, supported by field trips and use of a drone to investigate and validate the landscape and other components. Within landscape cartography, the use of these indicators and new ways of correlating data is appropriate, and requires care and validation. Facts that allowed to define the region as a complex landscape in the State of Maranhão, where the heterogeneity of the units is striking and consistent with the water potential and geomorphological complexity. The anastomosing and meandering drainage channels, lakes, lagoons and streams shape and define social and economic characteristics of the region. In the field work, we identified cattle and buffalo pastures; areas with rice plantations that modify and fragment the landscape of units periodically flooded near the mouth of the Pindaré River; and areas where forest vegetation is persistently affected by anthropic action, as the Indigenous Land of the Pindaré River. By applying the methodology and correlating the Synthesis Map, Landscape and water and geomorphological dynamics, we reached the objectives outlined and ratified the hypothesis raised at the beginning of the present article. Agriculture has been impacting and fragmenting the landscape of the lower course of the PRB, changing and reducing the its potential, as well as damaging the landscape functioning.

Based on the analyzes discussed here, an alert has been given to the public bodies, since the Baixada Maranhense presents significant water potential, and its water sources are one of the main income sources for its inhabitants. It is envisaged that this work may bring data and/or solutions to the difficulties identified in the landscape units, permeating geoecological sustainability. This, precisely, is the prism of Landscape Geoecology and Landscape Cartography.

One of the great contributions made by this article regarding the modeling of landscapes through GIS, is to find paths tied to the sequence and mode of interaction of the data. Using the method of landscape levels has enabled us to define relief as a prominent element and that guiding component in the compartmentalization of landscapes. From this, the compartmentalization is carried out according to the taxonomic level one wants to reach. This type of methodology becomes applicable in other areas of the Amazon, in floodable areas, as well as areas that have insufficient data, as is the case of this research region.

For this reason, the study aims to contribute by subsidizing data for the planning and physical-territorial management of the lower course of the Pindaré River, as well as supporting the future adoption of a committee for the Pindaré River Basin, facing its environmental, economic, and social potential.

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