APPLICATION OF GEOSPATIAL TECHNIQUES TO EVALUATE SOIL COVER AND LAND USE IN THE FLORES RIVER BASIN, MARANHÃO STATE-BRAZIL

Antonio Cordeiro Feitosa [1]; Robson Menezes da Fonseca [2]; Ulisses Denache Vieira Souza [2]*

[1] Universidade Federal do Maranhão (UFMA) – Departmento de Geociências. São Luís/MA, Brazil.
* Corresponding author: acfeitos@gmail.com

Received: Oct. 15, 2017 - Accepted: Dec. 12, 2017
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ABSTRACT: The constituting elements of land surface are the first visualized expressions in a landscape - land cover, which finishes a conjunction of potentialities capable of awakening man's interest for occupation and development of activities aimed at exploring the available resources. Land cover and the hydrological features of the Flores river basin in areas of Barra do Corda, Joselândia, Presidente Dutra, São José dos Basílios e Tuntum cities, mid-east region of Maranhão state, caused the construction of a dam to provide hydric resources and boost local development, bringing an intense and accelerated dynamic in the regional landscape. In the present paper the main landscape transformations in the Flores river basin between 1984 and 2014 caused by the dam's construction are analyzed. Methods used were based on the qualitative phenomenological approach to characterize the natural and human resources in the area. The spatial analysis was supported by the available geotechnologies, mainly SIG/SPRING, QGIS and TERRAVIEW. The land cover map with indication of the main elements and potentialities, the characterization of the main land uses, and the interpretation of the most recurring socioenvironmental phenomena caused by human activities were the results obtained. Landscape alterations in the Flores river basin implied that the original plant cover decreased due to unregulated occupation causing environmental and social damage regarding natural resources and human activities sustainability.

Key words: Land cover and use, flores river dam, Maranhão State.

APLICAÇÃO DE TÉCNICAS GEOESPACIAIS PARA AVALIAR A COBERTURA E USO DO SOLO NA BACIA DO RIO FLORES, ESTADO DO MARANHÃO - BRASIL

RESUMO: Os elementos constituintes da superfície terrestre configuram a primeira expressão visualizada da paisagem, a cobertura da terra, que encerra um conjunto de potencialidades capaz de despertar o interesse do homem para a ocupação e desenvolvimento de atividades orientadas à exploração dos recursos disponíveis. A cobertura da terra e a conjuntura hídrica do vale do rio Flores, em áreas dos municípios de Barra do Corda, Joselândia, Presidente Dutra, São José dos Basílios e Tuntum, região centro-oriental do estado do Maranhão, motivou a construção de uma represa para prover recursos hídricos com vistas ao desenvolvimento local, acarretando intensa e acelerada dinâmica da paisagem regional. No presente artigo, analisam-se as principais transformações da paisagem da bacia do rio Flores, no período entre 1984 e 2014, possibilitadas pela construção da represa. A metodologia empregada se apoia na abordagem fenomenológica de base qualitativa para a caracterização dos recursos naturais e humanos da área, com a análise espacial apoiada pelas geotecnologias disponíveis, principalmente o SIG/SPRING, QGIS e TERRAVIEW. Como resultados, foi obtido o mapeamento da cobertura, com indicação dos principais elementos e potencialidades, a caracterização dos principais usos da terra e a interpretação dos fenômenos socioambientais mais recorrentes pela implantação das atividades humanas. Conclui-se que as alterações da paisagem na área da bacia do rio Flores implicaram a redução da cobertura vegetal original através da ocupação desordenada, com danos ambientais e sociais quanto à sustentabilidade dos recursos naturais e das atividades humanas.

Palavras-chave: Cobertura e uso da terra, barragem do rio Flores, Estado do Maranhão.

1. INTRODUCTION

Space occupation by men is motivated by the offer of immediately use and easily accessed resources necessary for survival and safety, thus zones near water bodies with high diversity are prioritized. However, staying for a long time in a certain area depends on the supporting capacity of the available resources, which is influenced by actions and alternative possibilities to the supply problems. The progressive resource reduction implies dangers to man's permanence in a certain environment due to the reduction in quantity and quality of the available resources.

Water is a limited and vital resource to the satisfaction of human needs and its damning performed in rivers increase its availability for human supply. This water is used to support activities and expand human occupied areas around water bodies, particularly in the regions subjected to climate seasonality, such as the mid-east region of Maranhão state.

According to FONSECA (2016), hydrological resource control constitutes a recurring practice since the Old Age to equate problems caused by the irregular rain distribution and the consequent scarcity for supplying domestic and other human activities.

In Northeastern Brazil, the irregular rain distribution was already known to the primitive inhabitants, as well as the drought phenomenon which was first registered in the early 15th century. The Portuguese faced several drought related difficulties while exploring the region between Pernambuco and Ceará states to remove the French installed in Maranhão (MORENO, 2011).

Knowledge and the techniques employed by the Portuguese enabled the construction of the first weirs by farmers in order to store water and grant its availability in the extended drought periods. Catastrophes caused by the great droughts motivated planning actions of large public dams, which gained importance to hamper flooding, urban supply, and posteriorly being aggregated to generate power with the first hydroelectric power plant built in the late 19th century (ELETROBRÁS, 2017).

Diversity and intensity in the use of land cover in the dam's vicinities brought quick landscape transformations and commitment to quality and functionality of the water and biodiversity resources. Such impacts are analyzed by its influences on drainage behavior, flow rate, and the overall environmental equilibrium that all hydrographic systems and subsystems have (BRASIL, 2006; CHRISTOFOLETTI, 1979; 1980).

The occupation of these areas modifies the ecosystem structure, exposing the soil to several weather related impacts that can compromise food production and the refilling of the water table.

Considering the relatively regular high pluviometry indexes, Maranhão state has been neglected by planning and management of water resources, notably in regards of weir constructions. However, in the mid-eastern region of the state, rainfall seasonality does not exceed the amount needed to provide high irrigation rates during the dry season.

In addition to the relative hydric deficiency during the winter and spring months, recurring losses occurred due to Mearim river floods that annually affected medium and lower river cities, such as Pedreiras, Bacabal, Pio XII, Vitória do Mearim and Arari (COSTA et al., 2012). Major effects were felt by the Pedreiras population that suffered with the fast filling of the river caused by strong rains in both the river source and neighboring regions upriver where the upland landform accelerates drainage. In contact with the plains the fast drainage speed reduction occurs and river flow increases causing it to overflow.

One can argue that the referred dam construction was not motivated by problems related to the lack of water caused by climatic contingencies, but by its excess during the highly rainy periods, which caused floods and reached the river margin resident population causing material damage and loss of lives (FONSECA, 2016).

Inserted in the context of hydrologic resources policy idealized for the whole Maranhão state territory, the Flores river dam was built in the early 1960s and would represent the first step of the General Plan of Mearim and Tributaries proposal, which predicted the construction of other dams throughout the Mearim river course and its tributaries, namely Corda, Flores and Grajaú (GONÇALVES, 2007, FONSECA, 2016). This plan suffered to continue due to a lack of state policies to guarantee investments in the project.

The elaboration of the Mearim river General Plan implied on the performance of a survey to gather preliminary data and information obtained through field and cabinet research techniques. The option for the Flores river dam was motivated by its importance as one of the main Mearim river's tributaries. Controlling its drainage contributes to relieve its flow and would guarantee a water reserve to benefit activities in the reservoirs' vicinities. However, the resident population in the lower river would benefit with flood and material loss reduction which negatively affected their stay in the Maranhão state's center meso region (IBGE, 2008).

The present study aims at analyzing cover and land use alterations in the adjacent areas of the Flores river dam characterizing the environmental elements before its construction and the socioenvironmental processes that resulted from the human intervention on the landscape, notably between 1984 and 2014.

The study was developed with support of geotechnologies to build thematic maps of the areas with greatest occurrence of conserved natural resources and those which presented more evidences of human presence. Data were obtained through field activities by interviews carried out with the population that resides in the adjacent areas of the dam, enabling the comprehension of their problems in greater detail.

Integration of qualitative and quantitative data of the environmental segments delimited in the study area enables elaboration of tables and graphs that depict environmental changes that occurred in the dam's vicinities since its implementation.

Results demonstrate the need to rationalize human activities in the relationships between environmental factors and the constant use of new technologies to adequately intervene in ecosystem impact mitigation. These should be used to promote a continuous resource use according to the environmental sustainability principles

2. MATERIAL AND METHODS

The study was elaborated focusing on qualitative analysis, considering the possibility of applying multiple environmental indicators in environmental sustainability actions. To achieve the research goals the following methodological procedures were developed:

- Bibliographic and documental research about the man's intervention process in the Flores river landscape, notably those related to the construction and its impacts such as Environmental Impact Studies, the Environmental Impact Reports and follow up reports;
- Retrieving and analyzing satellite images from anterior and posterior periods to the dam's implementation, such as analysis of the occupied zones near the study area and its environmental alterations;
- Characterization of the area based on secondary data surveys regarding physical and socioeconomic elements of the region.

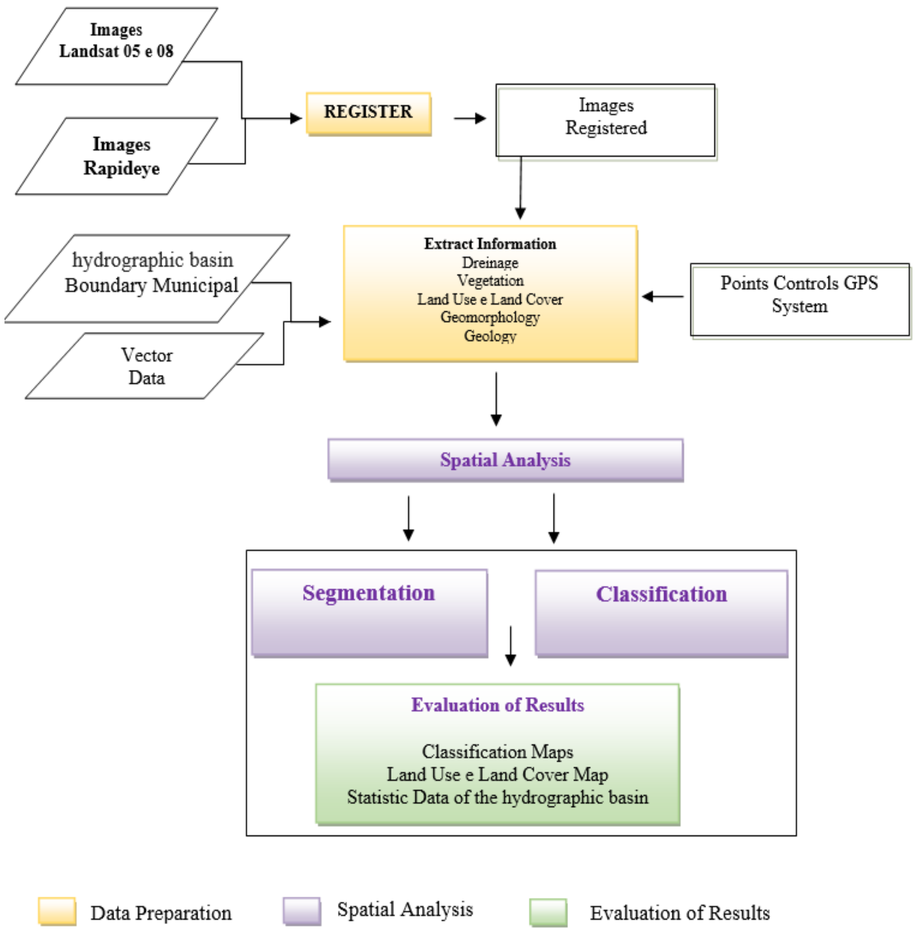


Figure 1. Methodological fluxogram.

- Identification of the cover and land use types to comprehend the current situation and the most significant transformations based on the river basin area history (SANTOS, 2004);

- Elaboration and application of semi-structured questionnaires to properly dimension resident perceptions about the impact of the environmental changes on their way of life. The questionnaire was applied to all dam vicinities' resident agricultures comprising land owners and those benefited with land zones.

Data obtained were used to elaborate maps and subsidize hydrographic basin plans once they enable an accurate visualization of the spatial distribution of elements in the environment and its potential for human activities.

LANDSAT satellite images from different times of the year were analyzed with the following fluxogram (Figure 1), and maps were made available by agencies that manipulate such images with application of geotechnologies as an essential element in the integration of the achieved results.

The Geographic Information System (GIS) was used as a tool to insert attributes and descriptive aspects of the geographic data (FINOTTI, FINKLER and SILVA, 2009), the Georeferenced Information Processing system – SPRING to elaborate the Numeric Elevation Model (NEM) and maps from DSG/MMEx to build work area images.

In a similar procedure carried out by EMBRAPA (2013) using the same free software used in this paper, SPRING and Qgis, images from the United States Geologic Service (USGS) were used with geometric correction and digital land elevation data (MDE).

The importance of planning and local data usage enables to acquire detailed information, gathering particular data for each region, increasing the value of natural resources and institutions that aim at better understanding men's relationship with its surroundings, which are constituted of population traditional activities.

Image segmentation and classification are used in governmental programs, such as works available by PRODES, PMDBSS and PROBIO with the support of MMA and EMBRAPA in 2011, better spatial resolution images from the RapidEye satellite, 2011.

In order to evaluate land cover modifications in the Flores river basin, the supervised soil use classification process was used. The years 1984 and 2014 were chosen before the dam's construction. To achieve better results, processes were elaborated by operations and numerical transformations of targets and classes in order to avoid information loss and data analysis mistakes (FLORENZANO, 2008). Image analysis consisted of pre-processing, enhancement, and image analysis steps (FLOREZANO, 2008; MENESES and MADEIRA NETTO, 2001).

The process of cover and land use mapping was elaborated through analogical interpretation of Landsat 5 and Landsat 8 satellite images, respectively, with TM and OLI sensors (Table 1). A 30m spatial resolution with a 30x30m geometric correction, corresponding to 1 pixel (BATISTELL, VALLADARES e BOLFE, 2008) was used applying remote sensing techniques.

3. RESULTS AND DISCUSSION

As results of the present study, the localization and geographic situation of the studied area, the cover and land use investigation obtained through the research steps in geographic literature records, as well as research agencies site exploration and field data are presented.

Table 1. Type and acquisition date of satellite images, 1984 and 2014.

LANDSAT 5	POINT	ACQUISITION DATE
TM19840620220063	220/63	23/07/1984
TM19840620220064	220/64	10/08/1984
TM19840627221063	221/63	23/07/1984
TM19840627221064	221/64	10/08/1984
LANDSAT 8	POINT	ACQUISITION DATE
LC82200632014190LGN00	220/63	10/09/2014
LC82200642014318LGN00	220/64	10/09/2014
LC82210632014245LGN00	221/63	23/09/2014
LC82210642014229LGN00	221/64	23/09/2014

The studied area corresponds to the Flores river basin, the main Mearim river tributary by the right margin, which extends for around 400 km and 5,808 km^2 area. Flores river basin is delimited by geographic coordinates at its extremes: to the north on the confluence between Flores and Mearim rivers at 04° 51’ 20” south; to the south at the Alpercatas ridge, a watershed with the Itapecuru river tributaries near the Brejo do Cazuza village at 05° 58’ 22” south, and by the meridians 44° 20’ 45” west near Crioli de Sinhá village within Graça Aranha city, and 45° 01’ 55” west near Escondido village within Barra do Corda city (Figure 2).

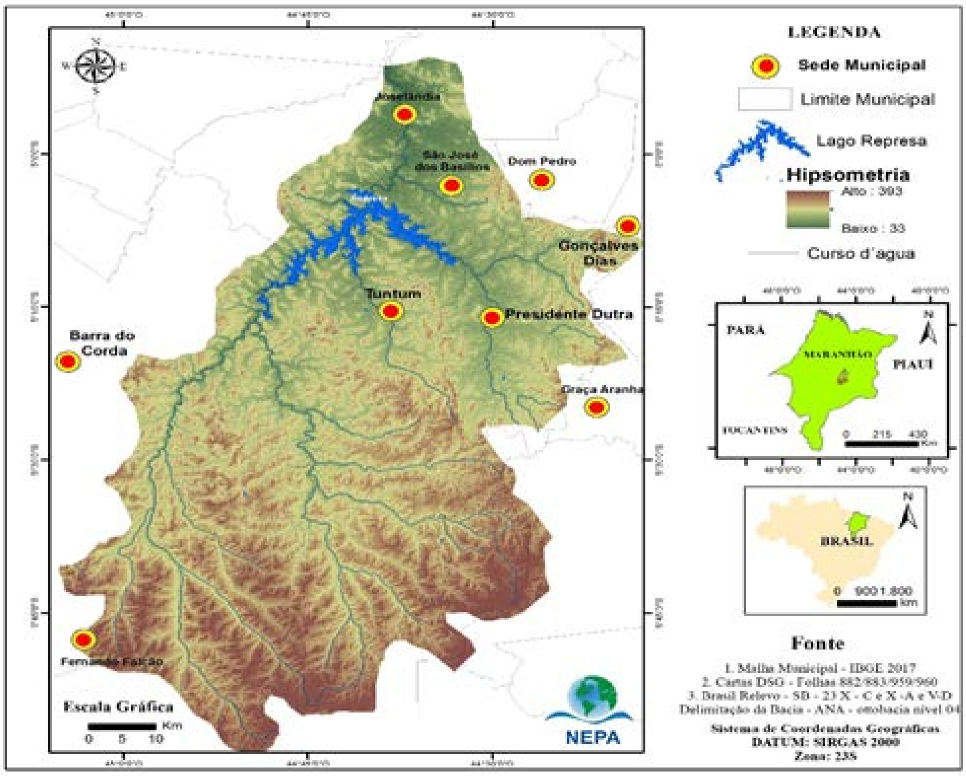


Figure 2. Study area localization.

Situated in the transition between upland and plain, and with an expressive setting on the south-north axis, the study area was maintained at the development margin in Maranhão until the 1970s when BR 135 opening and pavement enabled access to São Luís and Teresina cities following BR 226 construction, which eased the access to Southeast and Mid-Western regions of Brazil.

Geo-environmental composition comprehends the constituting elements of its natural landscape here approached in an order considered fundamental to comprehend the whole picture, both from the exclusive elements of land cover and for the potential use following the condition of human actors involved according to their historic time and space.

Cover and soil use approaches started in the beginning of first maps constructed using aerial photographs as the photographic interprets and scientist's objects of interest as a condition for carrying out more reliable studies. When computers and remote sensing techniques were incorporated, these professionals' role was redefined for digital processing with a significant gain of speed and quality, without preceding a professional with similar function – the analyst.

With the creation of the International Geosphere-Biosphere Program (IGBP) the first reflections in the sense of establishing narrow conceptual relationships between the significant emerged: cover, uses, and soil with more precise appropriations of their meanings, expressed by different modalities of human interventions upon nature. McConnel and Moran (2001), McConnel (2001) and Moran (2001) did the first elucidative approaches about these questions following such diffusion of ideas in the scientific community.

The referred approaches discriminate cover as a conjunction of biophysical environmental materials, use of products from the complex and diverse array of human activities and the soil as a thin layer of superficial land over which men performs its productive activities.

The geologic base of the Flores river basin fits the Parnaíba sedimentary basin in its lithology, which was originated in the Paleozoic and is stratigraphically composed of Mesozoic and Cenozoic sediments, with highlights for Corda formation from the Jurassic; Codó, Grajaú and Itapecuru, from the Cretaceous (FEITOSA, 1983) and overlapping with lateritic covers from the Cenozoic age (BANDEIRA, 2013).

The investigation of the predominant elements in land cover, the Flores river dam surrounding area enabled the elaboration of geological, landform, climate, plant cover, hydrography, and soil maps to dimension the potentialities and compatible uses with the established precepts in the federal, state and city environmental legislations.

Geological analysis offers data and information about the potential that natural resources have for human activities and orients its uses when associated to rocks and minerals, water, and soil evaluating the possibilities to improve socioeconomic and mineral reserves, conserve the quality of water bodies and soil's natural fertility (MOTA, 1997).

According to Fonseca (2016), the region's geological features conforms into one of the main sedimentary systems in mid-western Maranhão state, dominated by sedimentary strata with varied granulometry and consolidation. This determines its capacity to resist to fanning and to the speed in which morphological modifications occur through time under natural conditions and under human intervention (Figure 3).

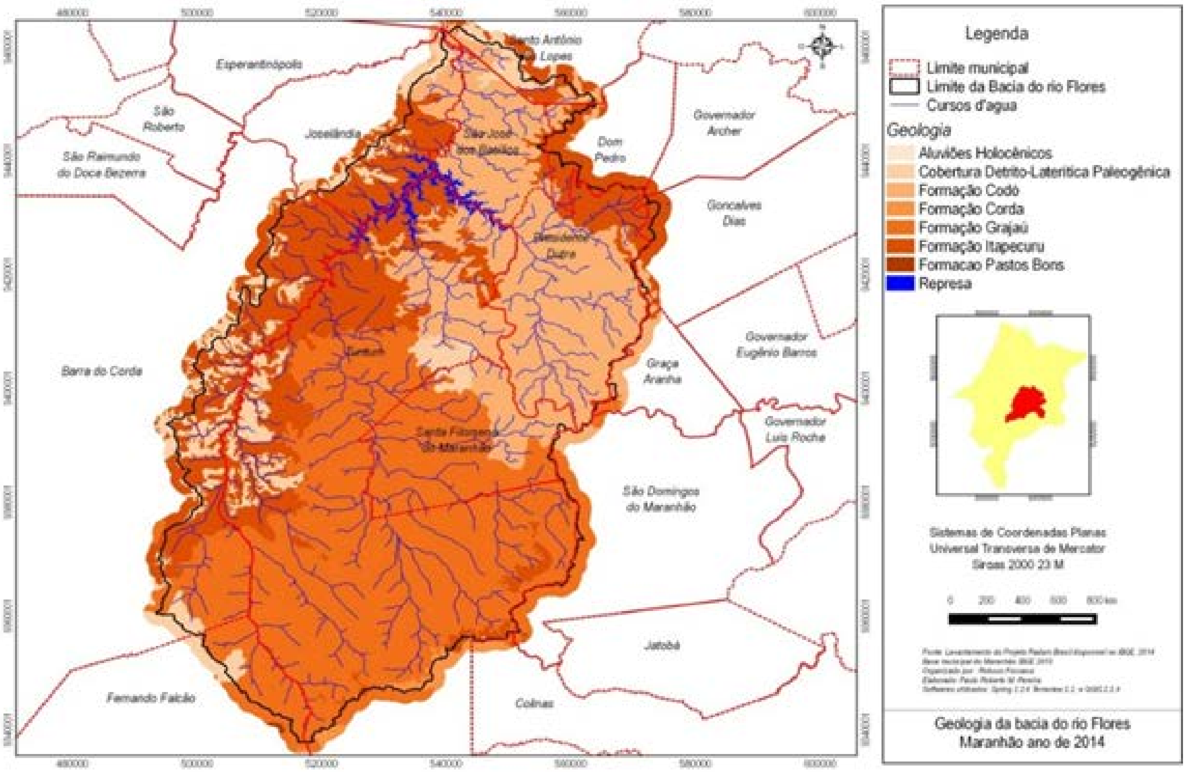


Figure 3. Flores river hydrographic basin geological map.

In the superficial layers, Itapecuru Formation's largest extension can be seen constituted by red sandstone with clay, intercalated by argilitos, siltitos and lateritic concretions while disperse points with lower topographic levels expose Grajaú formation's rocky outcrops with earthy material composed of sandstone, siltitos, and betuminous shales with relative economical potential for hydrocarbons, limestone and gipsita are being explored in some localities (MENDES e BORGHI, 2004).

Lithological diversity contributes to increase the array of exploratory options and its attributes evidence the modelling agents and their dominant processes as well as their resistance to erosive agents of the environments with river deposition nature (IBGE, 2011a).

In the area with direct influence of the Flores river dam water body, the Codó formation rocky outcrops are found with basal conglomerates overlapping with greenish to black shales, locally bituminous and pirituous with limestone intercalations and gipsita levels and fine grain sandstone (BANDEIRA, 2013).

In the geomorphological characterization of hydrographic basins, it is necessary to consider land modelling as referring to the main agents and morphogenetic processes acting, since the visible form of the land allows the deduction of its typology and intensity of weathering, erosion, deposition and sedimentation for the morphology and potential use of land coverage, subsidizing the interpretation of drainage, infiltration and flood-prone processes (SANTOS, 2004).

The different geomorphologic profiles of the Flores river basin highlight the stronger land desiccation on the path of the canals that characterize the draining network, shaping tubular and sub-tubular surfaces with edge breaks on different slopes and hills, which can offer gradual resistance to the weathering of rocks, in case there is a systematic re-occurrence of gaps in land coverage.

Since it represents a transition zone between the semiarid climate of the Northeast region and the humid climate of the Amazon (FEITOSA e SOUZA, 2017), the geomorphology between the Maranhense plateau and plain forms hill's topomorphological physiography, where the constant processes of physical weathering and erosion gave rise to valleys embedded with an intense drainage network, exposing the articulation of the hydrographic system to the geomorphologic one.

The tabular surfaces of the Itapecuru and Mearim river basins show, predominantly, cretaceous sandstone from the Corda and Itapecuru formations, with considerably old detrital-lateritic coverages, different from sandstone. The relief of the region shows the pluvial and fluvial modelling over the remaining lithogy desiccation agents of the Codó, Grajaú and Itapecuru formations, on the transition from the plain to the plateau (FEITOSA, 2006), forming low plateaus (AB'SABER, 1960) interleaved by valleys embedded on the medium courses of the Mearim river tributaries (BANDEIRA, 2013).

The topomorphological compartments are evidenced by the topographic gradient between the headquarters of municipalities with areas on the basin and on the vicinity of the dam. Considering the city of Joselandia, with an altitude of 35m, the following amplitudes appear: 59m in relation to São José dos Basílios, 77m to Presidente Dutra, 114m in relation to Barra do Corda, 140m in relation to Tuntum, and 178m to Santa Filomena do Maranhão.

The evolution of weathering and erosion processes at the studied area is associated with the resistance of lithologic structures to shear, on the transition zone from plateau to plain, which models the tabular "chapadas" and reliefs from the center towards the north of the state, making the physiognomy even more desiccated in hills.

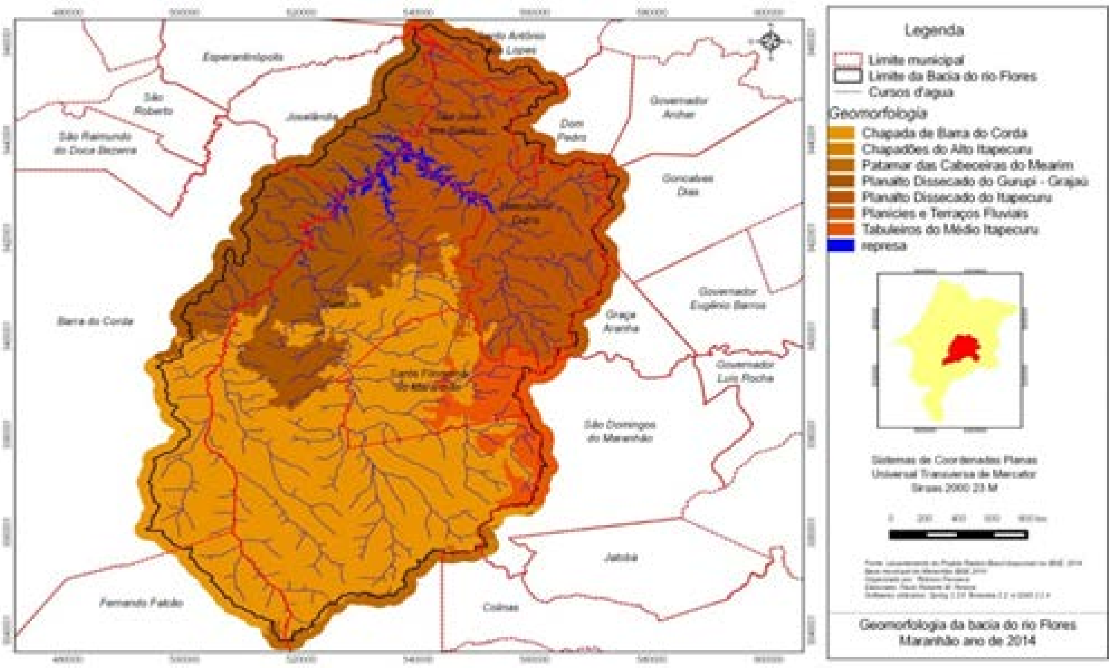


Figure 4. Geomorphologic map of the Flores river basin.

a) Hypsometric chart

b) Slope chart

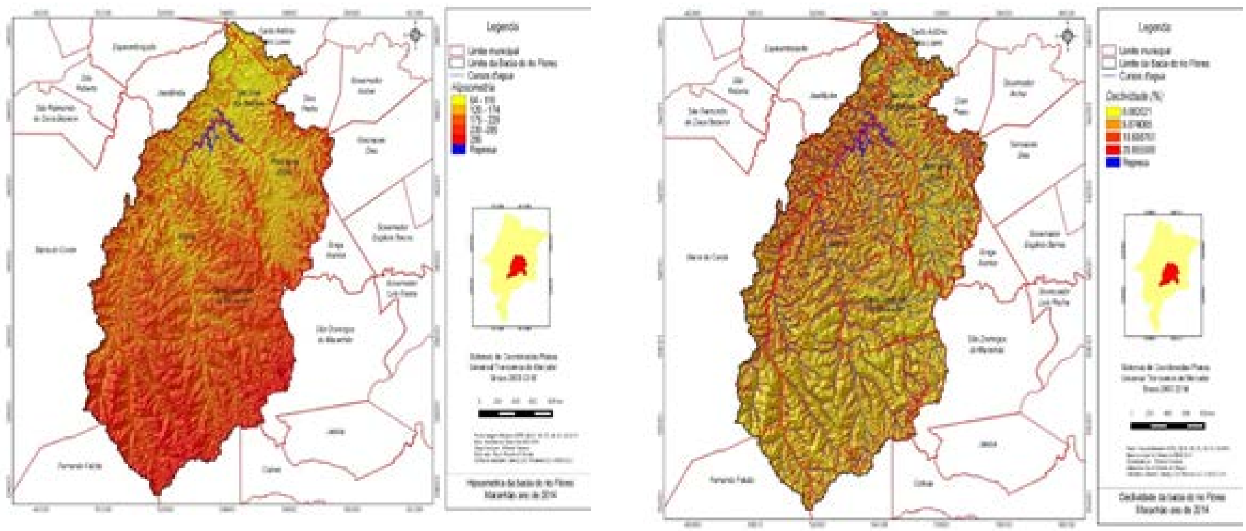


Figure 5. a) Hypsometric chart and b) Slope chart.

West of the Flores river, there is the oriental domain of the desiccated plateau (IBGE, 2011c), the valleys are more embedded and there is a higher density of draining on the tributaries' interfluvials of the left margin of the Flores river, and right margin of the Mearim river. Modelled in more modest quotes, they show a predominance of low wide plateaus and low desiccated plateaus, plainly carved by a draining network of medium and high density, a pattern of sub-dendritic to trellis, which highlights some sort of structural control on the desiccation process of these low plateaus.

The geomorphology around the reservoir is divided into two main compartments east of the Flores river, by the tabular and sub-tabular surfaces of the Itapecuru formation, with wider valleys and interfluvials and, west of the Flores river, by the border of the Gurupi-Grajaú Desiccated Plateau (IBGE, 2011b), with narrow valleys and interfluvials.

The dominant climatic variables at the Flores river area correspond to the thermal gradient with 15°C of amplitude and an annual average temperature superior to 25°C, predominant rainfall between 800 and 1200 mm, with irregular distribution that cause floods during the months of February and March (COSTA, NASCIMENTO e FEITOSA, 2012; FEITOSA, 2012; LOUZEIRO and FEITOSA, 2012), notably on atypical years. During the dry period, water shortages occur during winter and spring months, especially from July to October, and relative air humidity higher than 40%, shaping the sub-humid tropical climate.

Original forest coverage expresses the dominant pattern of the Cerrado from the North of Brazil with relict phytophysiognomies of the Cerrado, on the tabular and sub-tabular tops, and of the Cerradão on the baixões and wet slopes, distinguishing the gallery forests that border the riverbeds. Nowadays, plant coverage exposes the domain of secondary formations marked by agricultural activities and the extensive livestock (IBGE, 2011c).

The Flores river basin shows elongated configuration on the general south-north direction, with a relatively arched curvature on its main course to west, compensated by the draining of tributaries of the right margin. The main river has as its tributaries by the right margin the Preguiça, Cigana and Mucura rivers and the Tuntum stream, which bathes the homonymous city. The Cigana river has continuity upstream by the São Bento river until the Corredeira and Grande grotas, which supply the city of Santa Filomena (figure 6).

The left margin drainage is marked by significant structural control expressed by the intense desiccation of the terrain, which interferes on its development, with predominance of small courses on the scale of streams, named as grotas.

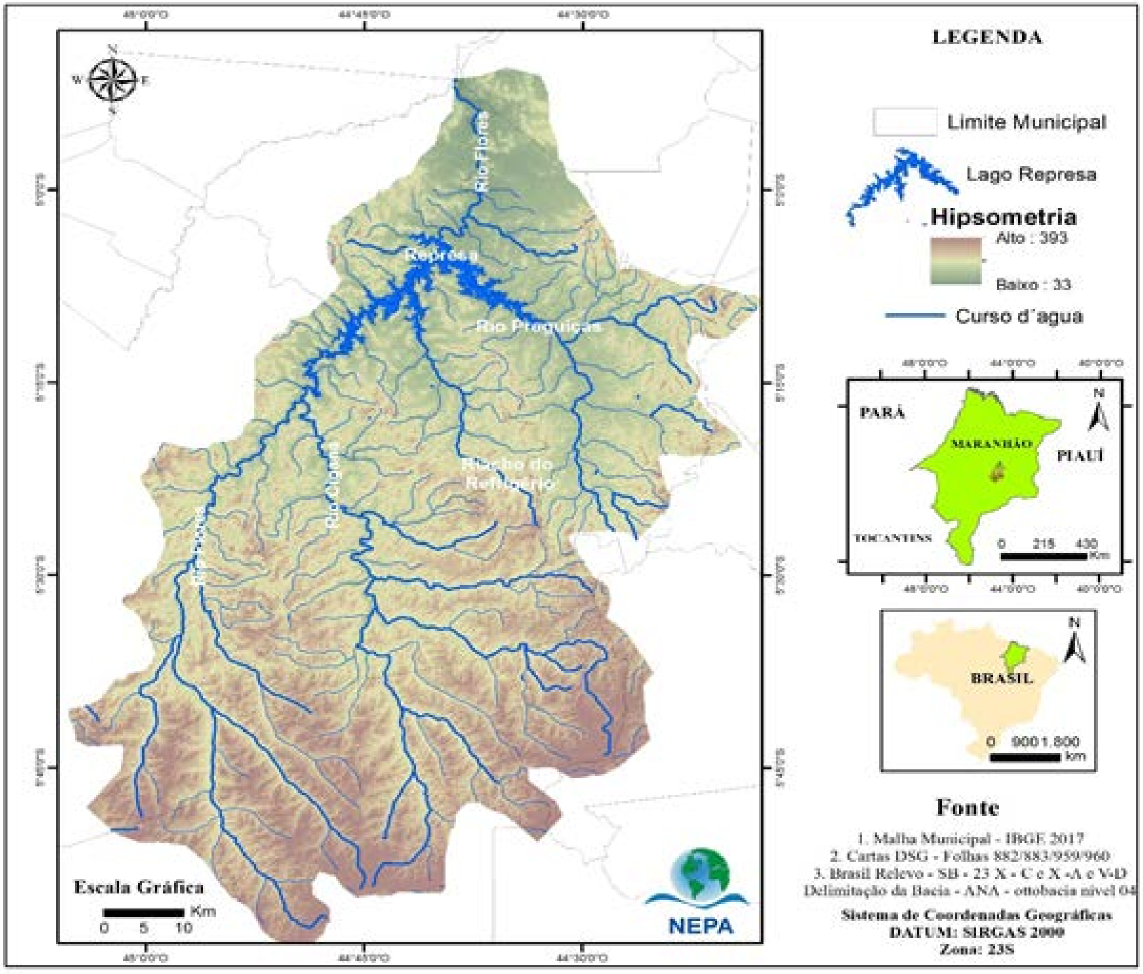


Figure 6. Hydrographic map of the Flores river basin. [Source: National Water Agency (ANA, from the portuguese Agência Nacional de Águas)].

At the hydrographic basin of the Flores river, the rivers that stand out are the main one, the Preguiças river, the Cobra stream and the Poço Verde, Grande and Martins igarapés (BANDEIRA, 2013), which drain to the Mearim river.

According to Fonseca (2016, p. 19), besides the Alpercatas and the Flores rivers, which drain the area from the Tuntum municipality, the rivers São Bento, Cigana and Mucura, and the streams of Lagoa, Jacaré, Mutuca, Campo Largo, Furrundugo, Pifeiros and Canafístula are important hydric courses at a local scale, and should receive special attention from management committees, notably the ones that drain the waters upstream to the dam, and which directly contribute to the lake's formation.

The geographic distribution of soil types can be represented in maps produced based on pedological surveys which consist on the inventory of soils present in a certain area (STRECK, 2008, p. 12). For the studied area, there are no detailed surveys on soils. However, some inferences can be made from small-scale mappings.

The lithologic system formed by structures with higher aluminium and iron contents give rise to strata more resistant to weathering, recurrent around the dammed area, in a shape of slightly corrugated hills, interspersed by valleys, on the transition from the plateau to the humid plain on the north of the state.

The regional pedological coverage results from the association of the elements from the sandstone, clay and silty base lythologies, forming soils with varied contents of organic matter, and of low and medium natural fertility, such as latosols, acrisols, quartzarenic neosols, and luvisols (Figure 7). External agents are the main modellers of the natural landscape on the Flores river basin, while climate is the main factor for modelling the Earth's surface.

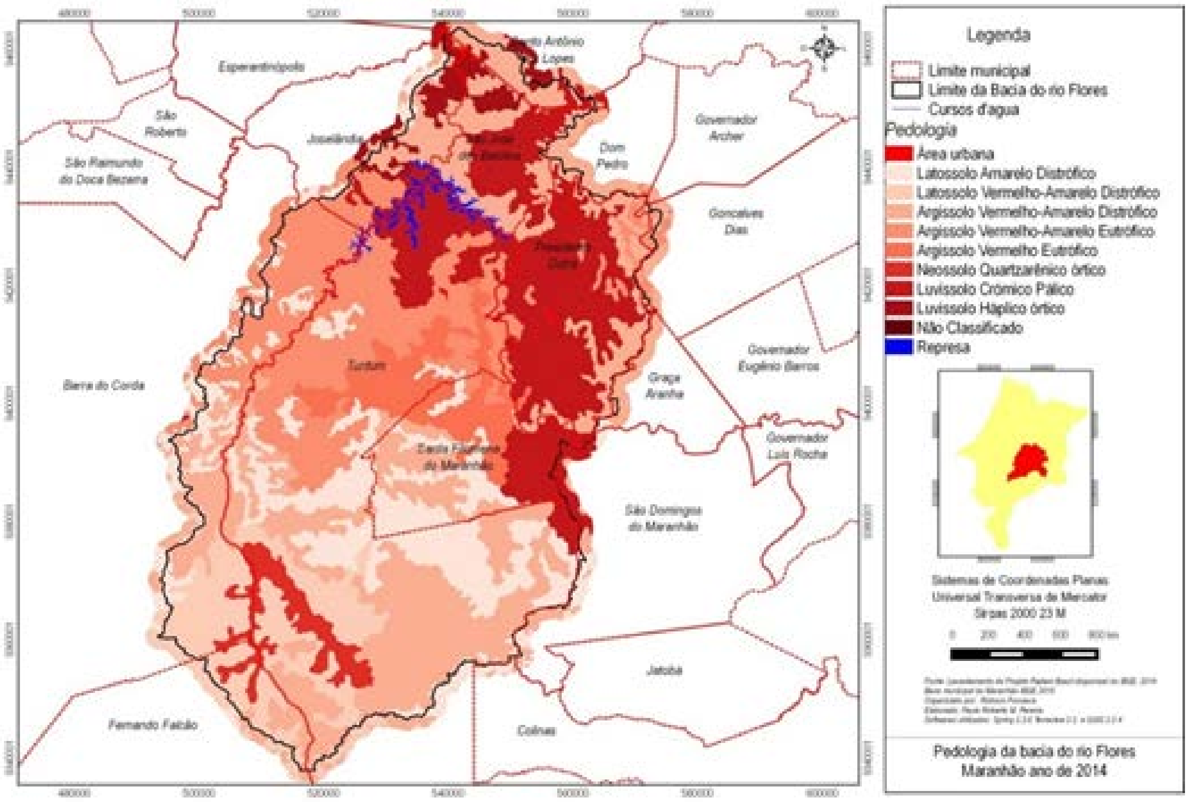


Figure 7. Map of the pedology of the Flores river basin

According to Bandeira (2013, p. 196), "areas with predominance of altered sandstone show high erosive potential", but the variety of lithology implies behaviour diversity on the processes of weathering, erosion, transport, deposition, and sedimentation, enabling the formation of acrisols, latosols, lithic neosols and poorly-drained plinthosols, with low to moderate nutrient retention capacity, and with physical characteristics and variable agricultural potential.

The presence of lateritic crusts on the upper portions of the desiccated plateaus, on the Cretaceous sandstone of the Itapecuru formation, shapes the deep and well-drained soils, the Dystrophic Yellow Latosols, besides other types more susceptible to erosion, such as the Eutrophic Red Acrisol, Eutrophic and Vertiginous Fluvial Neosols. On the surroundings of Presidente Dutra, São José dos Basílios and Tuntum, there are soils with good natural fertility such as Chromic Luvisols associated to Acriluvic Chernozem, Eutrophic Red Acrisols and Haplic Vertisols, correlated to outcrops of shales and limestones of the Codó formation (IBGE, 2011d).

At the vicinity of the Flores river reservoir, there are soils of medium and high natural fertility, with large concentrations of clay and heavily-weathered limestone, found near the city of Tuntum, with agricultural potential, since they are soils with "low erodibility and low resistance to cutting and penetration. Thus, they can become compact and waterproof when exposed to excessive mechanization and intense livestock trampling" (BANDEIRA, 2013, p. 212).

On flattened surfaces, developed from the bottoms of the valleys, Eutrophic and Dystrophic Haplic Plinthosol, Sórtico Quartzarenic Neosol and Dystrophic Natric Planosol (IBGE, 2011d), with abrupt texture gradient, high concentrations of clay-dispersing sodium, forming a sub-superficial horizon with columnar structure of imperfect draining (BANDEIRA, 2013).

Information on land use are important for planning and erosion susceptibility identification, groundwater contamination and the evaluation of the retention potential and water runoff speed. Soil acts as a support for the ecosystem and human activity. Knowing that it is necessary for the planning process, as it allows to deduct its potentiality and fragility as a natural element, a productive resource, a subsidy for human activities, or as an impact concentrator (SANTOS, 2004).

Human presence at the studied area recalls the settlement of the indigenous people Guajajaras, of semi-sedentary culture

(COUTO, 2011), followed by the conquest and occupation by Brazilian, on the mid-19th century, with the foundation of the Barra do Corda township (FERREIRA, 1959), beginning the exploitation of natural resources, and the development of subsistence activities.

According to Menezes (2016), the middle-east region of Maranhão has become better known after the construction of the highway BR-135, which allowed the flow of migrants from Northeast neighbouring states, mainly due to the strong droughts. On the second half of the 20th century, the construction of the Flores river dam represented a big incentive to agricultural activities in the reservoir vicinities, but systematic studies on the physiographic and population dynamics characteristics were not carried out, which still has repercussions in the face of the lack of information on the natural conditions around the Flores river dam.

The arrival of immigrants and the improvement of infrastructure enabled the growth and gradual modernization of the agricultural and livestock activities, contributing to accelerate the occupation process and the dynamic of land use at the Flores river region. The geographic space of the Flores river basin is occupied by 7 municipalities (table 1), of which only Santa Filomena do Maranhão and Tuntum are fully drained by the respective fluvial network, while Barra do Corda, Joselândia, Presidente Dutra, São José dos Basílios and Tuntum are related to the hydric body of the Flores dam, being directly benefited from these human interventions on the landscape.

Table 2. Characteristics of municipalities with total or partial area at the Flores river basin.

MUNICIPALITY	AREA (km²)	POPULATION 1980		POPULATION 2010		DEN. (hab/km²)	DHM 010
		Rural	Urban	Rural	Urban		
Barra do Corda	5.190	56.106	20.567	31.182	1.648	15,9	0,606
Fernando Falcão	5.087	*	*	7.735	1.506	1,8	0,443
Joselândia	681	13.214	3.276	9.473	5.960	22,6	0,561
Presidente Dutra	771	25.278	14.491	12.731	2.000	58	0,653
Santa F. do Maranhão	403	*	*	4.768	2.293	11,7	0,525
São José dos Basílios	353	*	*	4.490	3.006	20,7	0,557
Tuntum	3.573	25.278	9.421	21.256	7.927	11,6	0,572

Source: Adapted from Fonseca, 2016. *Municipality created in 1997

The intensification of productive activities represented an attraction for the population and the replacement of plant coverage for secondary forms, which expose the soil to alterations caused by modern agricultural practices and causes superficial sediment disaggregation, facilitating lixiviation. This fact bears negative consequences for the production, altering soil properties and the recovery of the ecosystem, thus facilitating

the spreading of invasive plant species, such as *babaçu*.

At cities closer to the dam, namely Presidente Dutra, Joselândia, São José dos Basílios, Tuntum and Barra do Corda, it was possible to observe the expressive growth in urbanization, compared to municipalities located further from the dam.

Data provided by older residents, that is, those established at the studied locations for more than 30 years, corroborated the evidence for areas with a stronger presence of *babaçu* palms, although there has been, in later years, a discrete reduction due to land flooding caused by the dam, and the removal of palms due to the plantation of pasture for cattle.

Quota show a 100-meter variation in altitude at the Northeast portion of the map, corresponding to the studied area, up until the “chapadas” down south, with quotas up to 350 metres, in which there is the Flores river spring and its main tributaries (figure 8). Many fertile areas, with altimetric heights close to 100m, that used to be cultivated and populated, have seen many social conflicts motivated by the flooding arise.

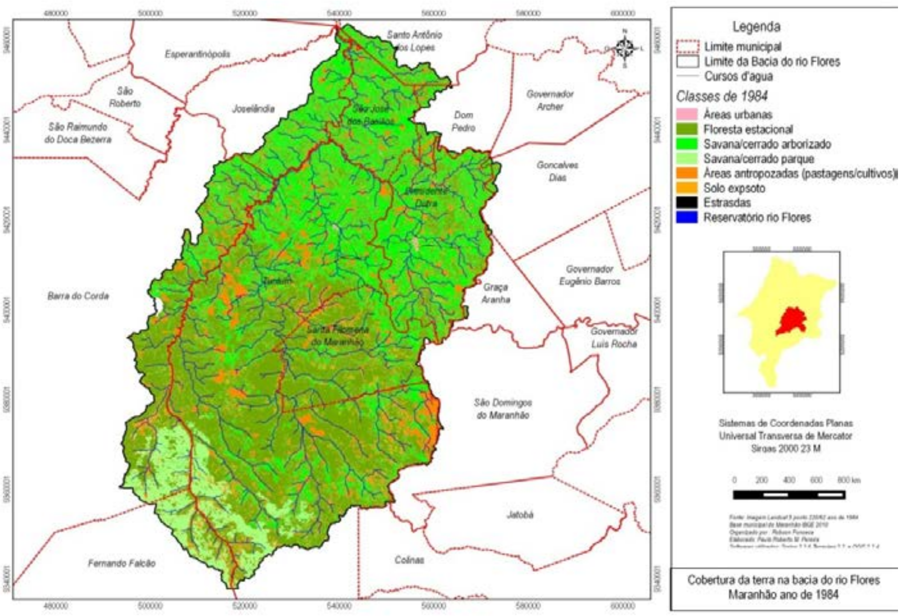


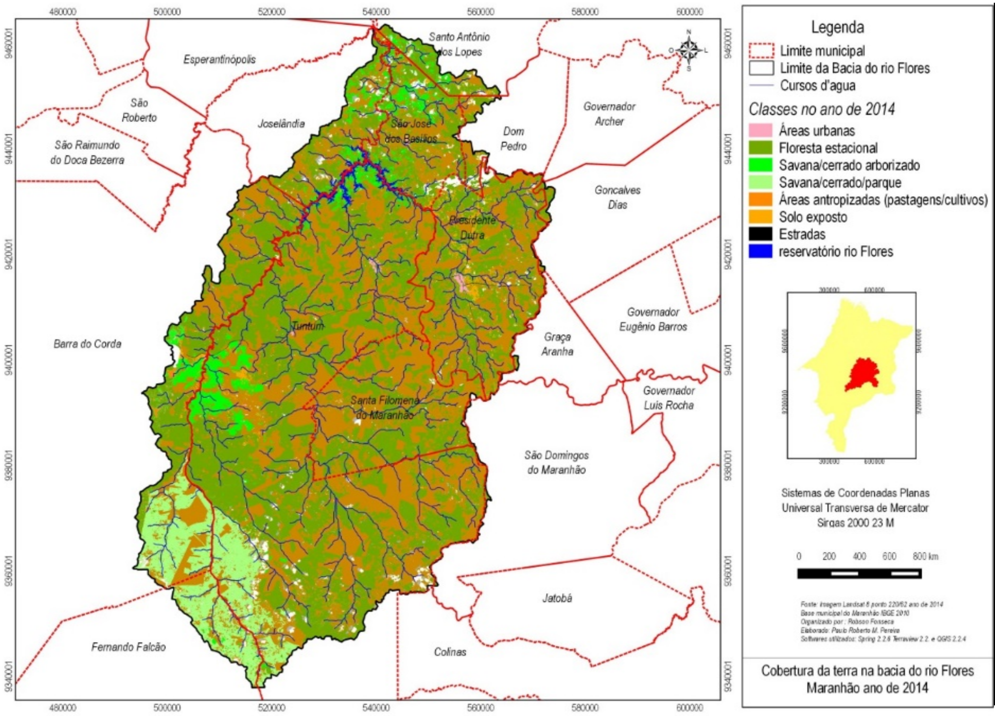
Figure 8. Land use at the Flores river basin: 1984 Source: Fonseca, 2016.

Livestock and agricultural activities are practiced without much land restriction, making evident the lack of adequate soil management practices, requiring monitoring by specialized technicians to reconcile the efficiency of productive systems with the environmental balance. The contest of theses technicians is more necessary in areas with greater slope, notably on the vicinity of the reservoir, where there is the possibility of considerable sediment input into river beds (PAIVA and PAIVA, 2001).

According to Fonseca (2016), until the 1980s the region presented great territorial extension with forest and *Cerrado* coverages only slightly altered, with natural diversity associated to water bodies. This situation motivated the occupation for agricultural and livestock activities, responsible for the main alterations on the *Cerrado*. As a consequence, a large part of the space occupied by forest and tree-cerrado vegetation was transformed into areas with strong human presence, concentrating native species at the marginal zones of water courses, forming a representative gallery forest, object of preservation and maintenance by the population, motivated by the committee of the Mearim river basin.

Upon analysing the area in 1984, alterations associated with the construction of the Flores river dam were noticed, but with no great relevance as the work was started in 1982, and was not finished until 1987. However, in 2014 the dam's water body showed an area of 3,898.26 hectares or approximately 39 km^2m, and a perimeter of 405 km in extension (figure 9).

Due to water availability issues in many municipalities, the systemic study of the area of the Flores river basin constitutes as an important tool for environmental planning. The great density of riparian forest shows its conservation on areas close to the water bodies, representing both the potentiality of these more fragile environments and the need to conserve them in order to guarantee the water reserve of the hydrographic basin (figure 9).



The most relevant alterations were the increase of occupied areas with anthropic use, especially livestock areas, in detriment of the tree-cerrado, which has species of economic value for civil construction.

Figure 9. Map of land use, Flores river basin: 2014. **Source:** Fonseca, 2016.

Areas used in activities for the construction of the dam, such as housing and allocation of construction materials, noted as exposed soil in 1984, showed reduction in 2014, transforming into pasture areas with grass and the presence of park-cerrado (table 3).

Table 3: Categories of land use at the Flores river basin.

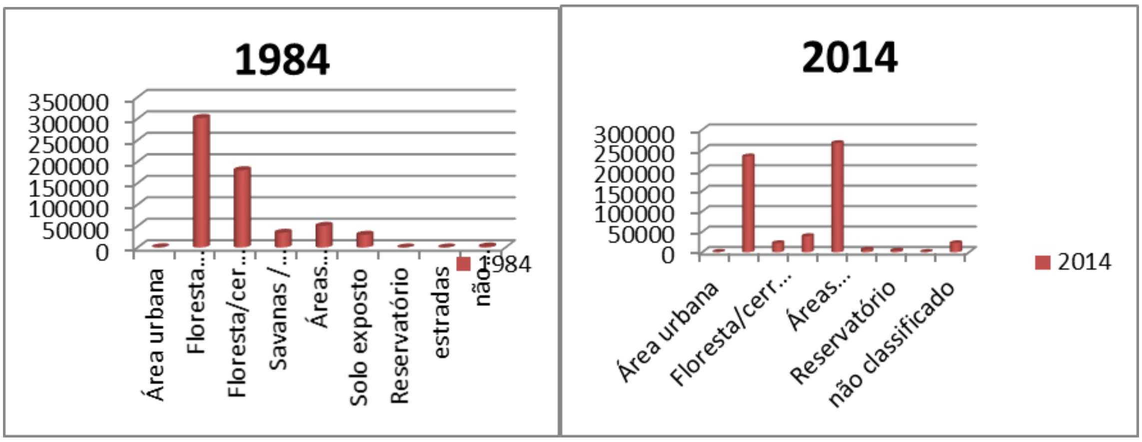
CLASS	1984		2014	
	Area^{ha}	Frequency	Area^{ha}	Frequency
Urban	374.14	0.1	913	0.2
Stationary forest	301,435.98	50.4	234,731.65	39.3
Forest/tree-cerrado	179,937.25	30.1	22,191.65	3.7
Savannah/ park-cerrado	34,177.88	5.7	39,574.75	6.6
Pasture/ crop area	50,330.21	8.4	267,367.73	44.7
Exposed soil	29,537.87	4.9	6,392.23	1.1
Reservoir	-	-	3,898.26	0.7
Road	14.84	0.0	705.37	0.1
Not-classified	2,281.41	0.4	22,314.92	3.7
TOTAL	598,089.58	100	598,089.58	100

Source: Fonseca, 2016.

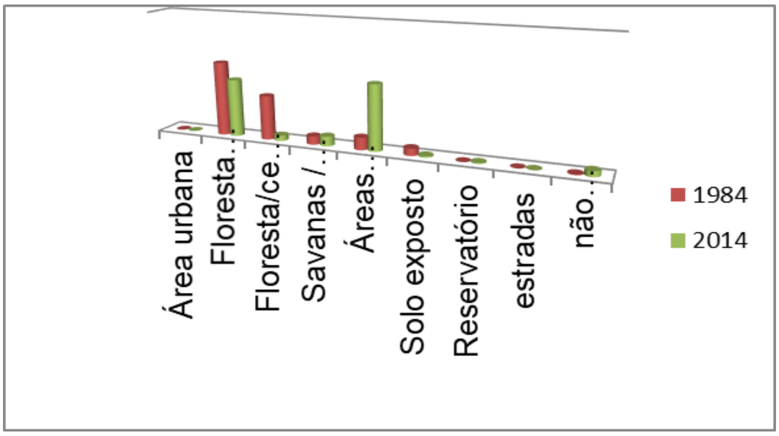
The urban area grew by an approximate 574 hectares, with a bigger representation at cities located close to the dam. This phenomenon is more recurrent at the municipal headquarters of Joselândia, São José dos Basílios, Tuntum, Presidente Dutra, and Santa Filomena do Maranhão. It should be noted that these municipalities have been receiving population increments associated to the discovery and exploitation of combustible mineral resources, with great repercussion on regional development.

The plant cover formed by tree species had the greatest reductions, originating a large extension of secondary vegetation well distributed along the studied area (graphs 1 and 2). The Seasonal Forest shows a vegetation of medium to high trees, and dense canopy.

Between the years of 1984 and 2014, there was a significant reduction of the exposed soil area, summing up to approximately 3% of the hydrographic basin, and a reduction in the stationary forest in approximately 66,704.3 hectares, with a percentage of 22% associated to the growth of human use areas with pastures. However, this class showed the highest representativeness for the year of 1984, and the second highest for 2014.



Graph 01: Land use area km^2 at the Flores river basin: 1984/2014. **Source:** Fonseca, 2016.



The savannah-park occupies the sector of highest altitudes, south of the studied area, sparse shrubs and undeveloped herbaceous vegetation predominate.

Graph 02: Land use in the studied area: 1984/2014.

The tree-cerrado corresponds to the environment with sparse vegetation, with predominance of grass and shrubs of low to medium height. This class showed the most significant reduction, from 30% in 1984 to 3% in 2014, a reduction of 157.774,6 hectares, by replacing areas of *Cerrado*, *cerradão* and forest by pastures.

Human use areas are characterized by the replacement of natural vegetation, notably for agricultural or pasture purposes (IBGE, 2006). This class increased by 37% between 1984 and 2014, in detriment of the *cerradão* with about 77% and, in smaller proportion, areas of stationary forest which occupy tabular and sub-tabular areas.

4. Conclusions

Based on the data and information analyzed on the present study, some conclusions can be established to contribute to the knowledge on the evolution of land coverage and use at the Flores river basin area. It is possible to subsidize new approaches related to the area occupation planning, namely on the dam surroundings, and the rational exploration optimization of natural resources and products from human activities.

The *Cerrado* biome is considerably important in this region of the state, needing larger studies in an attempt to better know its characteristics, structure and dynamics, for the preservation and conservation of ecosystems responsible for its biodiversity, the base of several sources of water availability and other ecosystem services.

The social and natural structures shape a diverse environment in relation to its neighboring communities, which needs a more thorough comprehension from men to promote land occupation and rational use.

That would be based on the fair distribution of land and on technical orientations to farmers regarding activity development and the reduction of conflicts that started after the implementation of the Flores river dam.

The occupation of areas too close to the water reservoir is made for the raising of cattle, traditional agriculture and human occupation, persisting the disrespect to legal occupations, allowing for eventual accidents with residents in these areas.

The generated maps on the human and natural conditions of the studied area represent water resource use and the areas around the dam, contributing with subsidies for natural resource and human activity management and their effects on the environment and socio-economy of the region, enabling a better visualization of the possible uses of space.

The synthesized information demonstrate the relationship between water resources and the area occupation around the Flores river dam, evidencing its importance to the water supply and to the use of other resources for present and future generations, which strengthens the preventive character of the study.

Lastly, the implementation of a new model of environmental management is suggested, one that prioritizes the detailed knowledge of the spatial variables and the potentialities of each category of environmental resource, both of natural origins and those resulting from human activities, with the support of Environmental Education.

5. REFERENCES

Ab'saber, A. N. Contribuição à geomorfologia do estado do Maranhão. Notícia Geomorfológica, Campinas, v. 3, n. 5, p. 35-45, 1960.

Bandeira, Isis Celeste do Nascimento (Org). Geodiversidade do estado do Maranhão. Teresina: CPRM, 2013.

Batistella, M., Valladares, G.S. E Bolfe, E. L. Monitoramento da expansão agropecuária como subsídio à gestão ambiental estratégica na região oeste da Bahia, Brasil. In: Batistella, M. and Moran, E. F., Eds., Geoinformação e monitoramento ambiental na América Latina. São Paulo: Ed. SENAC, 2008, pp. 163-195.

BRASIL. Ministério do Meio Ambiente. Avaliação ambiental integrada de bacia hidrográfica. SQA. Brasília, 2006.

ELETROBRAS. Linha do tempo da energia. Brasília: Eletrobras, 2017. Disponível: em: http://www.eletrobras.com/elb/services/eletrobras/trilhaenergia/pdfs/linha-do-tempo-da-energia.pdf. Acesso em 13 de setembro de 2017.

Christofoletti, Antonio. Geomorfologia. São Paulo: Editora Edgard Blücher, 1980.

Christofoletti, Antonio, Análise de Sistemas em Geografia. São Paulo: Hucitec – Editora da Universidade de São Paulo, 1979.

Costa, Cleynice C.; Nascimento, Elizeu S. Do; Feitosa, Antonio Cordeiro. Contribuição geomorfológica para análise e compreensão das enchentes do rio Mearim. In: SIMPÓSIO NACIONAL DE GEOMORFOLOGIA 2012, 9. Rio de Janeiro. Anais. Rio de Janeiro: UGB, 2012.

Couto, Jorge. A Construção do Brasil: ameríndios, portugueses e africanos, do início

do povoamento a finais do Quinhentos. 3 ed. Rio de Janeiro: Forense, 2011.

Empresa Brasileira de Pesquisa Agropecuária. Relatório do Diagnóstico do Macrozoneamento Ecológico-Econômico do Estado do Maranhão / Mateus Batistella, Édson Luís Bolfe, Luiz Eduardo Vicente, Daniel de Castro Victoria, Luciana Spinelli Araújo (Org.). Campinas, SP. 2013. 450 p.

Feitosa, Antonio Cordeiro. Potencialidades do relevo do Maranhão. In: LIMA, Roberta M. B. de F. e FERREIRA, Antonio J. de A. São Luís: Edufma, 2013. pp. 231-252.

Feitosa, Antonio Cordeiro. Condicionantes socioambientais para a ocorrência de catástrofes naturais no estado do Maranhão. In: SIMPÓSIO NACIONAL DE GEOMORFOLOGIA 2012, 9. Rio de Janeiro. Anais. Rio de Janeiro: UGB, 2012.

Feitosa, Antonio Cordeiro. Relevo do estado do Maranhão: uma nova proposta de classificação topomorfológica. In: SIMPÓSIO NACIONAL DE GEOMORFOLOGIA, 6, 2006, Goiânia. Anais... Goiânia: UGB, 2006.

Feitosa, Antonio Cordeiro. O Maranhão Primitivo: uma tentativa de reconstituição. São Luís: Editora Augusta, 1983

Feitosa, Antonio Cordeiro e SOUZA, Ulisses Denache Vieira de. Variabilidade do clima tropical no Norte e Nordeste do Brasil. La Paz-Bo, XVI Encuentro de Geografos de America Latina. Anais. La Paz, 2017

Ferreira, Jurandyr Pires. Enciclopédia dos municípios Brasileiros. Rio de Janeiro: IBGE, 1959.

Finotti, Alexandra R.; Finkler, Raquel e Silva, Maurício D´Agostini. Monitoramento de recursos hídricos em áreas urbanas. Caxias do Sul: Educs, 2009. 272 p.

Florenzano, Tereza Gallotti. Iniciação em sensoriamento remoto. São Paulo: Oficina de Textos, 2007.

Florenzano, Tereza Gallotti. Sensoriamoto para geomorfologia. In: Florenzano Teresa Galloti. Geomorfologia: conceitos e tecnologias atuais. São Paulo: Oficia de textos, 2008.

Fitz, Paulo Roberto. Geoprocessamento sem complicação. São Paulo: Oficina de Textos, 2008.

Fonseca, Robson Menezes da. Alterações na cobertura e uso da terra no entorno da barragem do rio das Flores, Joselândia-Maranhão. São Luís: PPGSE-UFMA, 2016. Masters thesis.

Gonçalves, Jean Carlos. A Barragem do rio Flores: esperança e desilusão para o município de Tuntum. Monografia do Curso de Pós-Graduação apresentada às Faculdades Integrada FACVEST. 2007.

Instituto Brasileiro De Geografia E Estatística. Geologia: mapa geomorfológico do estado do Maranhão. Rio de Janeiro: IBGE, 2011a. Escala: 1:1.400.000.

Instituto brasileiro de geografia e estatística. Geomorfologia: mapa geomorfológico do estado do Maranhão. Rio de Janeiro: IBGE, 2011b. Escala: 1:1.400.000.

Instituto Brasileiro De Geografia E Estatística. Vegetação: mapa vegetação do estado do Maranhão. Rio de Janeiro: IBGE, 2011c. Escala: 1:1.400.000.

INSTITUTO BRASILEIRO DE GEOGRAFIA E ESTATÍSTICA. Solos: mapa de solos do estado do Maranhão. Rio de Janeiro: IBGE, 2011d. Escala: 1:1.400.000

Louzeiro, Andreza Dos S.; Feitosa, Antonio Cordeiro. Catástrofes Naturais no Estado do Maranhão: Os casos dos Municípios afetados pelas enchentes do rio Mearim. In: SIMPÓSIO NACIONAL DE GEOMORFOLOGIA 2012, 9. Rio de Janeiro. Anais. Rio de Janeiro: UGB, 2012.

Mcconnell, w. Land Use and Cover Change. In: Smelser N, Bates P (eds): The International Encyclopedia of the Social and Behavioral Sciences. Oxford: Elsevier Science: (2001).

Mcconnel W. J.; Moran, E. F. (eds). Meeting in the Middle – The Challenge of Meso-Level Integration. An International Workshop, October 17-20, 2000, Ispra, Italy (= LUCC Report Series; 5). – LUCC Focus 1 Office, Indiana University: Bloomington, 2001, 68 p.

Mendes, Marcelo Da S. E Borghi, L. Análise faciológica da formação Codó, Cretáceo bacia do Parnaíba, em testemunhos de sondagem. Anais... 3º Congresso Brasileiro de P&D Petróleo e Gás. Salvador: IBPG, 2004.

Meneses, P. R.; Madeira Netto, J. S. Sensoriamento remoto: reflectância dos alvos naturais. Universidade de Brasília. Brasília – DF. Embrapa Cerrados, Planaltina – DF, 2001. 262p.

Moran, E. Progress in the Last Ten Years in the Study of Land Use/Cover Change and the Outlook for the Next Decade. In: Diekman A, Dietz T, Jaeger CC, Rosa EA (eds): Human Dimensions of Global Change. MIT Press: Cambridge, 2001.

Moreno, Diogo de Campos. Jornada do Maranhão por ordem de sua Majestade feita no ano de 1614. Brasília: Edições do Senado Federal. 2011. Volume 161.

Mota, Suetônio. Introdução à Engenharia Ambiental. 1997. 1 ed., Rio de Janeiro, ABES. 292 p.

Paiva, J. B. D. de; Paiva, E. M. C. D. Hidrologia aplicada à gestão de pequenas bacias hidrográficas. Porto Alegre: ABRH, 2001. 625 pp.

Santos, R. F. dos. Planejamento ambiental: teoria e pratica. São Paulo: Oficina de Textos, 2004. 184 p.

Streck, E.V. Solos do Rio Grande do Sul. 2.ed. Porto Alegre, RS: EMATER, 2008. 222p. United States Geological Survey (USGS).

<http://earthexplorer.usgs.gov/>. Accessed in January 10th, 2015, at 08h30min.