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Caracterização geoambiental de uma bacia hidrográfica situada no Médio-Parnaíba piauiense

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RESUMO

Pesquisas ambientais podem ser elucidadas a partir da análise integrada dos geossistemas. Desse modo, é de suma importância entender as características geoambientais que representam os elementos naturais e que compõem o espaço físico, por constituírem a base para a compreensão da estruturação, planejamento e ordenamento territorial. Nessa perspectiva, objetivou-se caracterizar os aspectos geoambientais da bacia hidrográfica do rio Mulato/PI (BHRM). A coleta de dados compreendeu levantamento bibliográfico, aquisição de bases de dados, pesquisa de campo e produção cartográfica. Os dados foram explorados qualitativamente, sendo a caracterização geoambiental da BHRM fundamentada na abordagem sistêmica. Como resultados, realizou-se inicialmente o cruzamento entre as informações geológicas-geomorfológicas, contando ainda com dados referentes a declividade, aspectos hidroclimáticos, pedológicos, vegetacionais e de uso e cobertura do solo. A investigação dos elementos formadores do ambiente natural serviu para conhecer sua dinâmica, bem como os processos atuantes, visto que, a ação humana é, em muitos casos, o fator determinante para a estabilidade/instabilidade dos ambientes. Sendo assim, as características geossistêmicas analisadas e interpretadas, foram capazes de refletir as potencialidades e fragilidades do sistema natural pesquisado. Depreendeu-se, portanto, que pesquisas de caracterização geoambiental se tornam cada vez mais necessárias, pois colaboram de maneira consistente, com o reconhecimento aprofundado da área, posto que, esse tipo de estudo, aliado aos mapeamentos dos aspectos físicos-naturais, constitui ferramenta essencial em avaliações ambientais estratégicas, especialmente, em casos de intervenção humana.

Palavras-chave: meio ambiente, perfil ambiental, rede de drenagem.

Geoenvironmental characterization of a hydrographic basin in the Médio Parnaíba piauiense

ABSTRACT

Environmental research can be elucidated from the integrated analysis of geosystems. Thus, it is extremely important to understand the geoenvironmental characteristics that represent the natural elements and that compose the physical space, as they constitute the basis for understanding the structuring, planning and territorial planning. In this perspective, the objective was to characterize the geoenvironmental aspects of the Mulato River basin (MRB), in Piauí. Data collection included a bibliographic survey, acquisition of databases, field research, and cartographic production. Data were qualitatively explored and the geoenvironmental characterization of the MRB was based on the systemic approach. As a result, geological and geomorphological information were crossed, also using slope, hydroclimatic, pedological, vegetational, and land use/land cover data. The investigation of the elements that form the natural environment served to know its dynamics, as well as the acting processes, since human action is, in many cases, the determining factor for the stability/instability of the environments. Thus, it was inferred that the analyzed and interpreted geosystemic characteristics were able to reflect the strengths and weaknesses of the researched natural system. Hence, geoenvironmental characterization research becomes increasingly necessary, as they consistently collaborate with the in-depth recognition of the area, since this type of study, combined with the mapping of physical-natural aspects, constitutes a tool essential in strategic environmental assessments, especially in cases of human intervention.

Keywords: environment, environmental profile, drainage network.

Introduction

With the increasing pressure of human beings on the environment, the environmental issue has become one of the main concerns of society, since human actions are accelerating and modifying the behavior of natural processes. (OLIVEIRA, 2007; DIAS et al., 2019).

As it is the main scenario of interrelationships in environmental systems, the geographic space cannot be understood in a fragmented way, since it corresponds to a broad and integrated system, and must be understood in a holistic way, in the midst of a systemic reality (BRITO; TEIXEIRA, 2017; PAIVA; MEDEIROS, 2019).

In this context, environmental studies can be elucidated from the geoenvironmental approach, as it aims at the integrated analysis of geosystems (CHRISTOFOLETTI, 1979; RIBEIRO, 2017). Researches of this nature are based on the idea of interaction between the environmental variables of the natural environment and the forms of land use and occupation, proposing to identify impacts and changes in natural dynamics (SALES et al., 2020).

In this sense, it is extremely important to understand the geoenvironmental features that represent the natural elements and that form the physical space (geology, geomorphology, hydroclimatic aspects, pedology, vegetation, use and land cover), since they constitute the basis for the understanding of territorial structuring, planning and ordering (ALMEIDA JUNIOR, 2021).

The use of geotechnologies, mainly the Geographic Information System (GIS) and remote sensing products, has been relevant in the geoenvironmental characterization, allowing the compartmentalization and subsequent analysis of the geographic space (NASCIMENTO; SANTOS, 2020). These tools, besides helping to understand the topography of the analyzed area, help to identify possible environmental impacts, as well as support projects for the conservation/preservation of natural resources, with emphasis on hydrographic basins. (PEREIRA et al., 2019).

By integrating the processes that occur in the strands, the hydrographic basin is adopted as a territorial unit for planning and management purposes in different parts of the world (CAPOANE et al., 2022). Thus, it assumes a

substantial role in carrying out environmental diagnoses, since in addition to gathering information from the physical environment, it also groups those related to the anthropic environment, thus being able to be used for environmental monitoring purposes (COSTA et al., 2019).

In this scenario, the Mulato River basin (MRB) is inserted, located in the state of Piauí, which has been suffering strong anthropic pressures resulting from the movement of the agricultural frontier, especially in its upper river course. This expansion has been noticed by the local populations, which have already been impacted by the damage resulting from the replacement of native vegetation and the introduction of chemical supplies in this type of production.

Thus, when considering the importance of interconnecting data referring to natural and anthropic conditions, facing the planning and organization of the territory, the following question was elaborated: do the geoenvironmental characteristics contribute to the understanding of the dynamics of the geographic space? The guiding hypothesis indicates that the environmental characteristics allow to clarify the aptitudes and restrictions of the geographic space, as they serve as a subsidy for the management of natural resources. In this sense, the objective was to characterize the geoenvironmental aspects of the RMB/PI, so that this information translates the patterns of land use and occupation based on the elaboration of georeferenced images.

Methodological Procedures

Study area

The MRB is an important sub-basin of the main drainage axis in Piauí (Parnaíba River), inserted in the Mid-North mesoregion of Piauí and in the Médio Parnaíba Piauiense microregion (IBGE, 2020). It covers an approximate area of 1,049.13 km² and a perimeter of approximately 213.5 km. It comprises, in whole or in part, eight municipalities in the state of Piauí: Amarante, Angical do Piauí, Hugo Napoleão, Jardim do Mulato, Palmeirais, Regeneração, Santo Antônio dos Milagres, and São Gonçalo do Piauí (Figure 1).

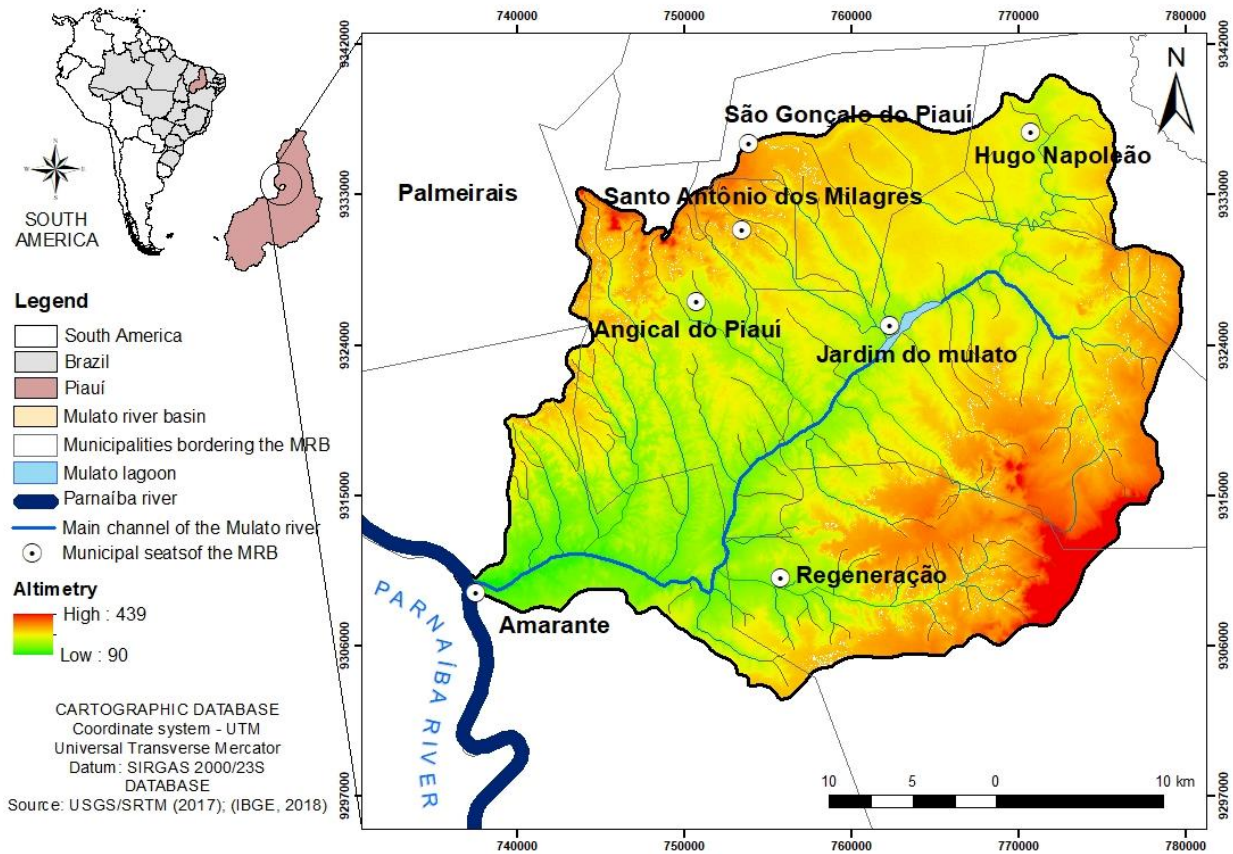


Figure 1. Mulato River hydrographic basin located in the state of Piauí, Brazil.

The Mulato River has its springs located in the municipality of Jardim do Mulato and runs in the Northeast-Southwest direction, until flowing into the Parnaíba River, in the urban area of the municipality of Amarante. The main tributaries are

the Riachão, Sambaíba, Baixa, Rodeado, Jurubeba, Gameleira, and Mulato streams (Figure 2). It also comprises a perennial natural lagoon with an area of approximately 21.68 km² and a perimeter of 11.25 km (Figure 3).



Figure 2. Spring of the Mulato stream located in the locality Coco, municipality of Regeneração/PI. A - Panoramic view of the spring of the Mulato stream. B - Spring points emerging at the Mulato stream head.



Figure 3. Mulato Lagoon located in the municipality of Jardim do Mulato/PI. Source: Author, in March 2017.

As it is an important drainage, from an economic and social point of view, for the population that depends on this natural resource, this fluvial system was chosen for the present investigation since it has been used, together with its tributaries, for the subsistence of a set of family nuclei.

Data collection

Data collection comprised the following stages: bibliographic survey, acquisition of databases, field research, and cartographic production.

With regard to information related to the geoenvironmental characterization of the MRB, searches were carried out in technical documents, scientific articles, and specific literature, in addition to maps and shapefiles, available in databases of official bodies at the municipal, state, and federal levels.

Hydrological modeling was used for boundary delineation of the surface drainage, using a digital elevation model (DEM) and visual interpretation of satellite images, having as subsidy the shaded relief. Subsequently, a raster of the water flow direction was generated, followed by the vectorization of the drainage network.

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For the geological cartographic product, data were obtained from the Mineral Resources Research Company (CPRM, 2010).

The geomorphological mapping was prepared based on data from the RadamBrasil Project (Brasil, 1973), using Sheet SB-23 Teresina and Sheet SB-24 Jaguaribe, in addition to satellite images from the Landsat 8 Operational Land Imager (OLI) and DEM.

Hydroclimatic data were obtained from the National Water Agency (ANA, 1992) and comprised an 11-year interval (1992-2002). Spatialization was possible through conversion of isohyet lines into pluviometric reference points.

Pedological information was acquired from the Spatial Data Infrastructure (INDE, 2014), following the guidelines proposed by the Brazilian Soil Classification System of the Brazilian Agricultural Research Corporation (EMBRAPA, 2013).

Finally, the land use and land cover map was prepared using data from Mapbiomas (2019). Agricultural information from the Brazilian Institute of Geography and Statistics (IBGE, 2017) was used to validate the data.

The cartographic bases in shapefile (shp) format were redesigned for the Universal

Transverse Mercator (UTM) Coordinate System, horizontal Datum SIRGAS 2000 and South 23 zone, being elaborated in a scale of 1:100,000, in a Geographic Information System (GIS) environment using ArcGis 10.5 (student license).

Data analysis

The collected data were explored through a qualitative approach and the geoenvironmental characterization of the MRB was based on the geosystemic approach of Bertrand (1972). For this author, the geosystem can consist of a spatial-territorial unit that can be delimited and analyzed with a method that implies carrying out holistic and integrated studies. In this sense, the fragmentation of information was discussed only in the background, giving priority, therefore, to systemic analysis.

Results and Discussion

The MRB is based on the lithostructural setting of the Parnaíba sedimentary basin whose geological formation originated from the Carboniferous (360 million years) to the beginning of the Cretaceous (150 million years), when the

platform's reactivation processes took place. The geotectonic event that gave rise to the southern part of the Atlantic Ocean promoted the reworking of preexisting rocks, the formation of faults in the terrains of the South American platform and the Parnaíba sedimentary basin, through the development of the fault zone of the trans-Brazilian lineament (Schobbenhaus and Neves, 2003).

During the geological periods of formation and evolution, this structural unit was affected by tectonic movements originating from internal forces of the globe. Specifically in the state of Piauí, records of these movements can be seen at the edge of the sedimentary basin, where plateaus of the cuestas type are observed, as well as in the folds and faults of rock conglomerates, present in some areas. These, in turn, form localized fractures of small and large extensions (Araújo, 2006).

In this context, the drainage network of the MRB results from the trans-Brazilian lineament and is based on an environment of sedimentary structure, with formations dating from the Paleomesozoic: Piauí (37.70%), Pedra de Fogo (11.87%), Sardinha (16.17%), Pastos Bons (0.04%) and Corda (38.21%) (Figure 4) (Lima, 1987).

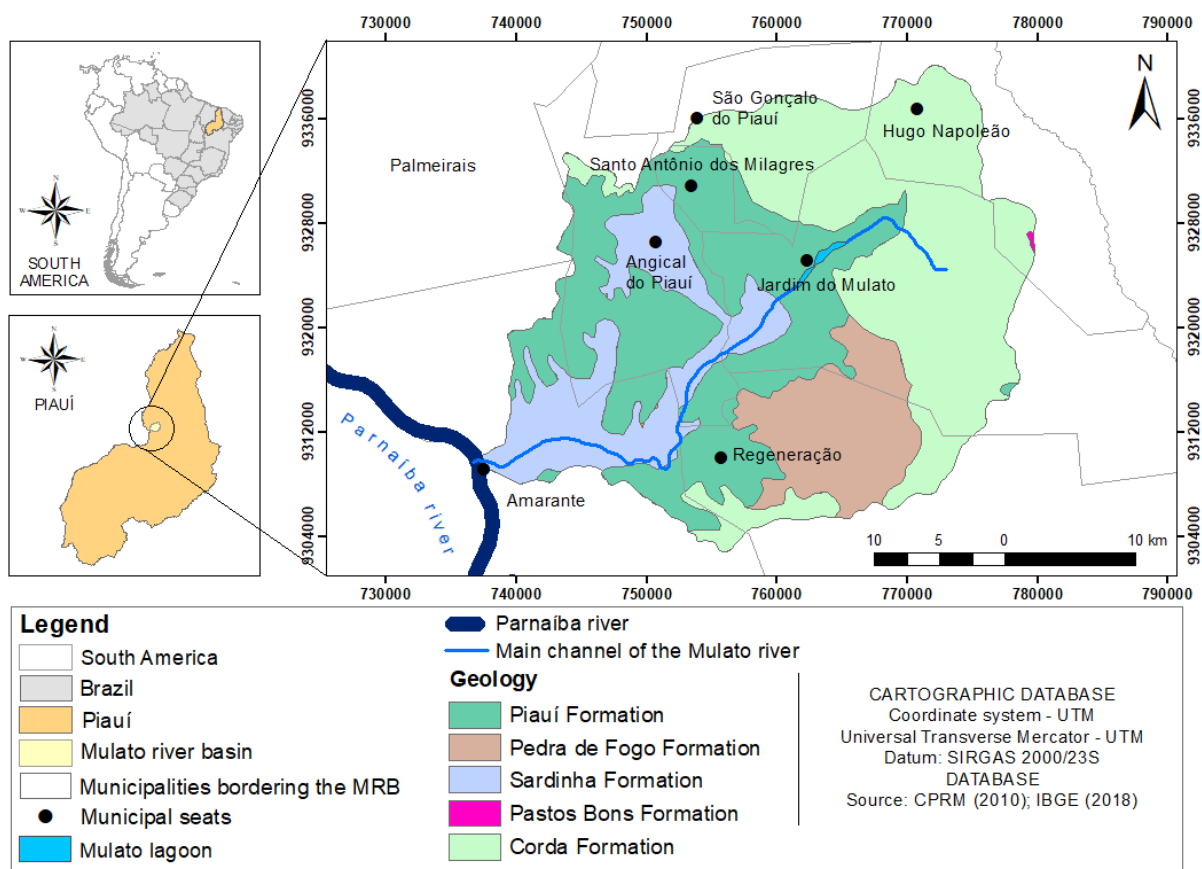


Figure 4. Geological characteristics of the Mulato River basin, state of Piauí.

The Piauí Formation dates from the Carboniferous (360 million years), consisting of aphanitic sandstones with thin and sometimes arenitic stratification, with conglomerates and cross bedding (Brasil, 1973; CPRM, 2010).

The Pedra de Fogo Formation of Permian age (300 million years) is composed of intercalated sandstones, siltstones and shales, in addition to conglomerates and pebble banks (quartz) (Brasil, 1973; CPRM, 2010).

The Sardinha Formation from the Cretaceous emerged from magmatic extrusion from normal faults of the São Francisco and Descanso. This gave rise to diabase sills and dykes, generally dark in color. The texture varies from aphanitic basalt, with spheroidal foliation, to gabbro, coarser, due to weathering actions (Brasil, 1973; CPRM, 2010; Spisila, 2011).

The Pastos Bons Formation, in turn, dates from the Triassic (250 million years) and is composed of a sequence of shales and sandstones of varied texture, which promote good water retention capacity (Brasil, 1973; CPRM, 2010).

The Corda Formation of the Cretaceous period is composed of sandstones, siltstones and shales, located on the paleodepressions of the diabases of the Sardinha Formation, and discordant contact with the older geological formations (Brasil, 1973; CPRM, 2010; Pfaltzgraff et al., 2010).

Regarding the surface relief forms of the MRB, they come from the development of normal faults (São Francisco and Descanso) from the municipalities of Amarante/PI and São Francisco do Maranhão, oriented in the Northeast-Southwest direction. In addition to regional faults, fractures occur throughout the sedimentary basin, which ends up reflecting on the behavior of relief forms, including local ones (Lima, 1987).

Based on the dynamics of these faults, two blocks were segregated: Southeast and Northwest.

The first, in relation to the fault, lowered itself towards the second and brought into contact, in the area of the municipalities that make up the MRB, the Piauí and Pedra de Fogo formations, giving rise to the lines of weakness and volcanic spills (Brasil, 1973).

Thus, starting from the physiognomic aspect, which is based on origin and age, the relief forms can be classified up to the fourth taxon, according to the taxonomic levels of Ross (1992). For this author, Geomorphology is based on the concepts of morphostructure and morphosculpture, with the understanding that current landforms undergo an adequate interpretation of current and past endogenetic and exogenetic influences.

In this context, the morphostructure of the Parnaíba sedimentary basin comprises the first taxon, formed by essentially Paleomesozoic sedimentary rocks. This is considered the most expressive form of relief; its genesis and chronology are older than the geomorphological features carved in its interior. The second taxon (morphosculptural units) reflects the regional relief forms, in which the climate allows their individualization and classification. The third taxon (morphological units) is related to a given physiognomic aspect, which comes from the influences of more recent erosion processes. The fourth taxon, finally, refers to each of the relief forms that fit into the morphological units and the MRB therefore comprises three morphological units (High Residual Relief Surface, Reworked Residual Relief Surface, and Fluvial Plain), which include the Low Plateaus of the Middle-Lower Parnaíba (Group of Mesas and Witness Hills of the Mesa Type, Lowered Plateaus, and Fluvial-lacustrine Plain), whose altitudes range from 90 to 440 m between its low and high fluvial course (Figure 5) (Lima, 1987).

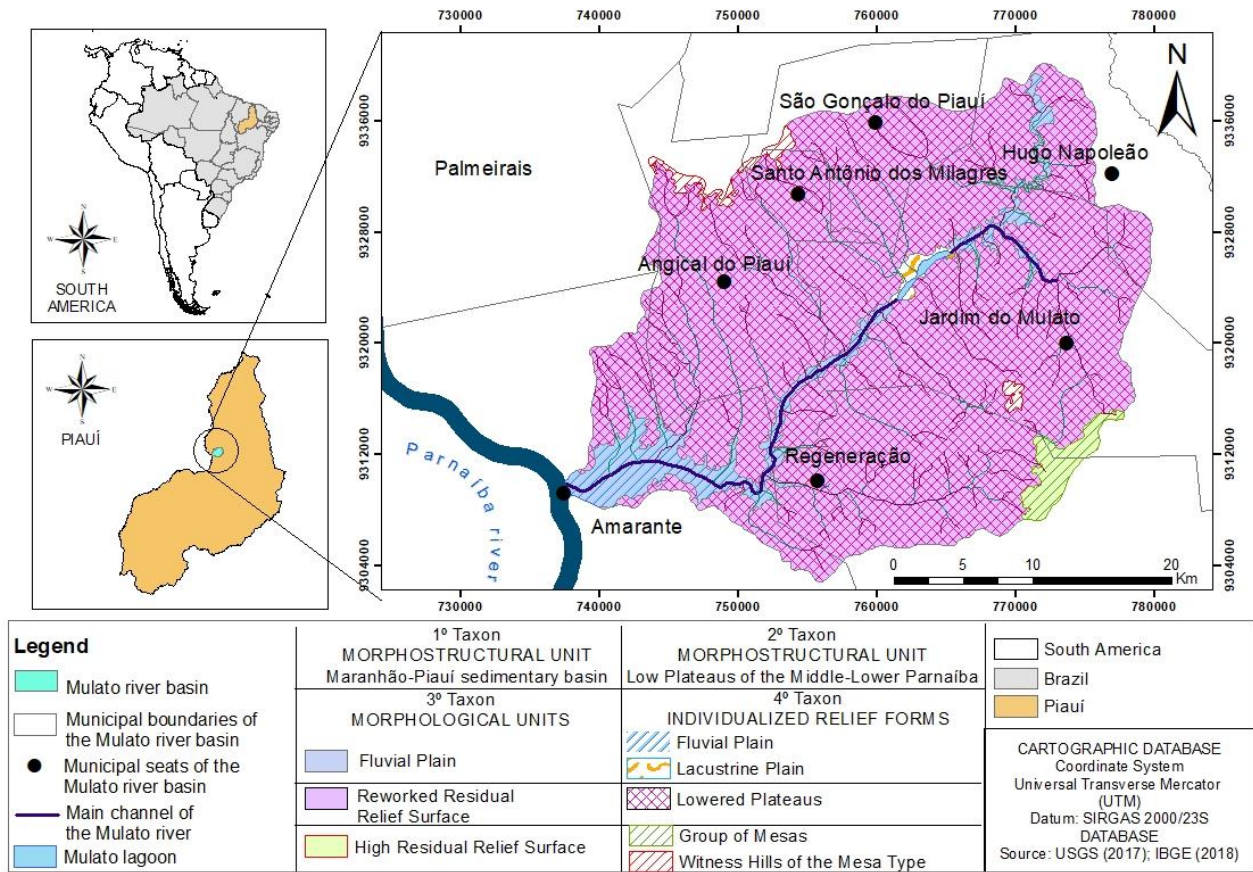


Figure 5. Geomorphology of the Mulato River basin, Piauí state.

The slope can be influenced by the relationship between rainfall and runoff in the hydrographic basin, which can interfere with the speed of surface runoff and water infiltration into the soil. Thus, the slope and vegetation cover become important factors in the decision making of an adequate management of the hydrographic basin, since they influence the effective precipitation, surface runoff and water flow in the soil (SILVA et al., 2018).

Based on the slope map of the MRB (Figure 6), there was a predominance of flat to smoothly undulated reliefs throughout the extension of the basin, with the most significant slope class being 0% to 12%. In these sectors, the terrain has a horizontal topography, with almost non-existent unevenness, especially along the fluvial plains.

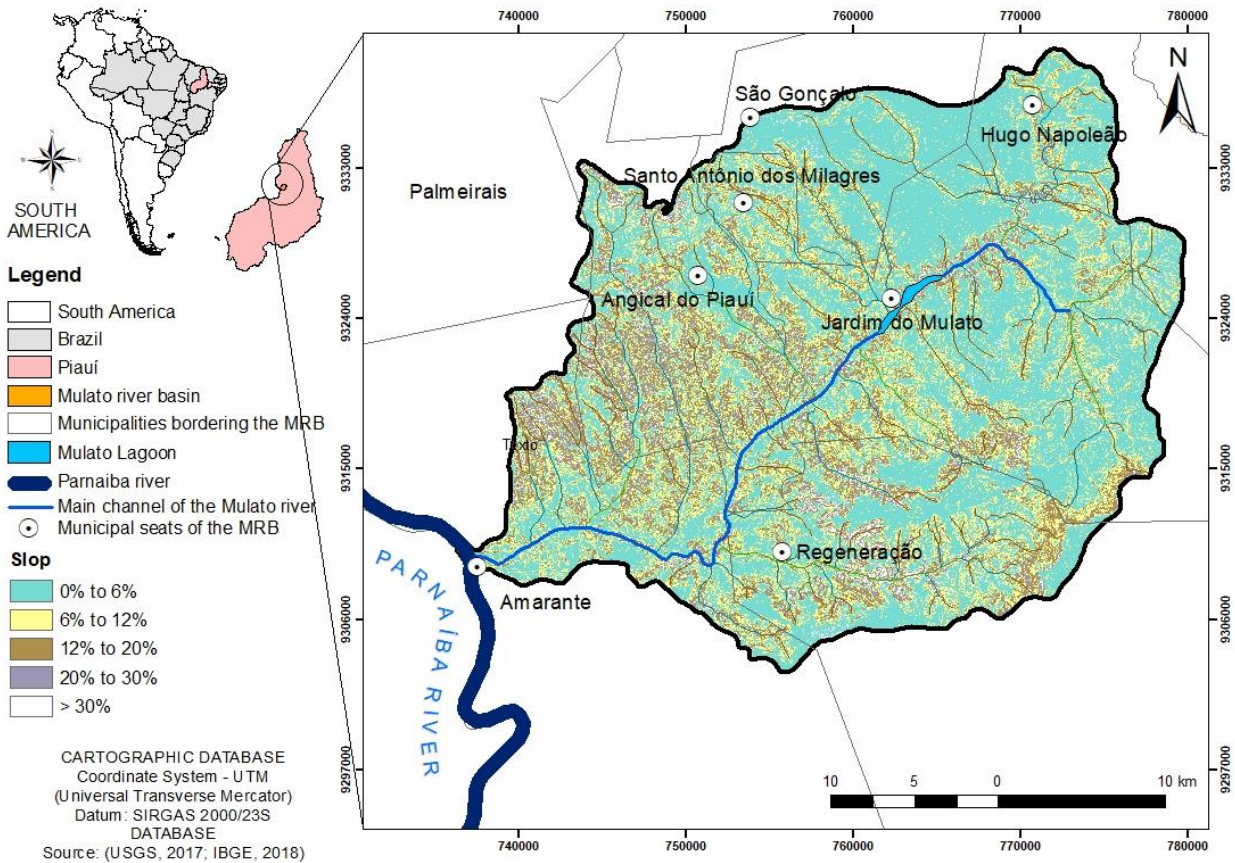


Figure 6 - Slope of the Mulato River basin, state of Piauí.

Slopes between 12% and 30% also extend across the entire basin, especially close to water courses, where slopes range from 20% to 30%. In the first class, the terrain presents little motion and consists of low plateaus, with a smooth slope, showing initial solifluction and diffuse and laminar flow. In the slope class of 20% to 30%, the terrain also presents little motion, but has a steeper slope than the previous class, consisting of hillsides, with predominance of laminar flow, ravines, and gravitational mass movements. In turn, the slope class above 30% consists of tabular plateaus, where block movements are common.

According to Ross (1994), slope values indicate the characteristics of the relief that generate potential energy for the occurrence of geomorphological processes, such as laminar erosion and landslides.

Mass movements consist of the displacement of certain volumes of soil. Among the main mass movements, soil slips or landslides stand out (Luzivão et al., 2020). In general, they are responsible for the interdictions of highways, originating from floods, and are therefore associated with slope instability (Futai, 2017; Gersovich, 2016; Sbroglia, 2015).

The climate is another important variable in geosystemic studies, as it is one of the primary

controllers in different mechanical processes of terrestrial modeling. This is because atmospheric processes have a strong influence and complexity in comparison to other elements of the environment (Ritter et al., 2002). Thus, climate - based on rainfall dynamics - is considered an essential variable to understand potential fragility.

Atmospheric conditions, in general, are established by the circulation of atmospheric air through mechanisms such as: redistribution of heat and humidity and air movement across the globe (Ferreira and Mello, 2005). Thus, ecodynamic instability processes are associated not only with the quantity, but also with the concentration of water available for surface water flow in a given period of time. For this reason, the greater the annual rainfall and the shorter the duration of the rainy season, the greater the susceptibility to erosion processes (Crepani, 2001; Spörl and Ross, 2004).

Knowing that atmospheric systems restrain and influence the rainfall, it is necessary to understand the climate dynamics of the sector under analysis.

From this point of view, the MRB is subject to the influence of a semi-arid (hot and dry) climate characterized by spatiotemporal intermittence of rainfall and high temperatures

throughout the year (Köppen and Geiger, 1930). In summer, most rains (90%) are concentrated in the first half of the year (January to March), with a mean rainfall ranging from 900 to 980 mm. In turn, in winter, during the other months of the year (June to September), rains are irregular, with means of 117 to 180 mm.

The atmospheric mechanisms behind regional rainfall dynamics are related to the Intertropical Convergence Zone (ITCZ), South

Atlantic Convergence Zone (SACZ), Polar Front (PF), Easterly Waves (EW), Upper Tropospheric Cyclonic Vortices (UTCVs), Squall Lines (SL), Mesoscale Convective Complex (MCC), and El Niño – southern oscillation (Ferreira and Mello, 2005; Zanella, 2014).

Regarding the mean annual precipitation isohyets of the MRB, they varied from 1,134 to 1,319 mm between the low, medium, and high fluvial courses (Figure 7).

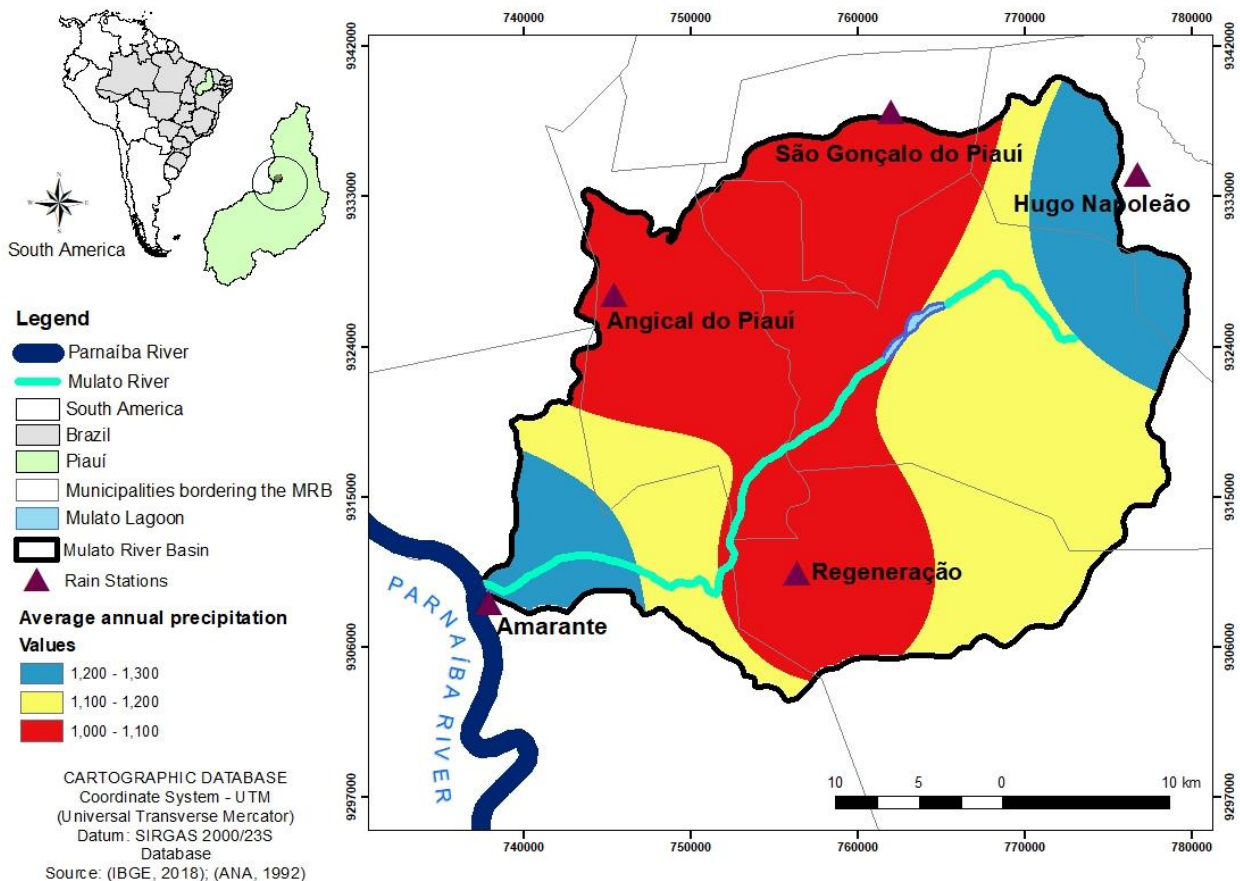


Figure 7. Mean rainfall in the Mulato River basin, state of Piauí.

As it is a natural element, precipitation is not quantitatively evenly distributed in the space in different periods of the year, although some places are expected to receive higher frequency and quantity of rains (Rodrigues, 2020).

Temporal-spatial variations in rainfall are directly related to climatic conditions and these, in turn, exert a strong influence on surface or underground water resources. Thus, it is extremely important to summarize the hydrological characteristics of the MRB (Figure 8).

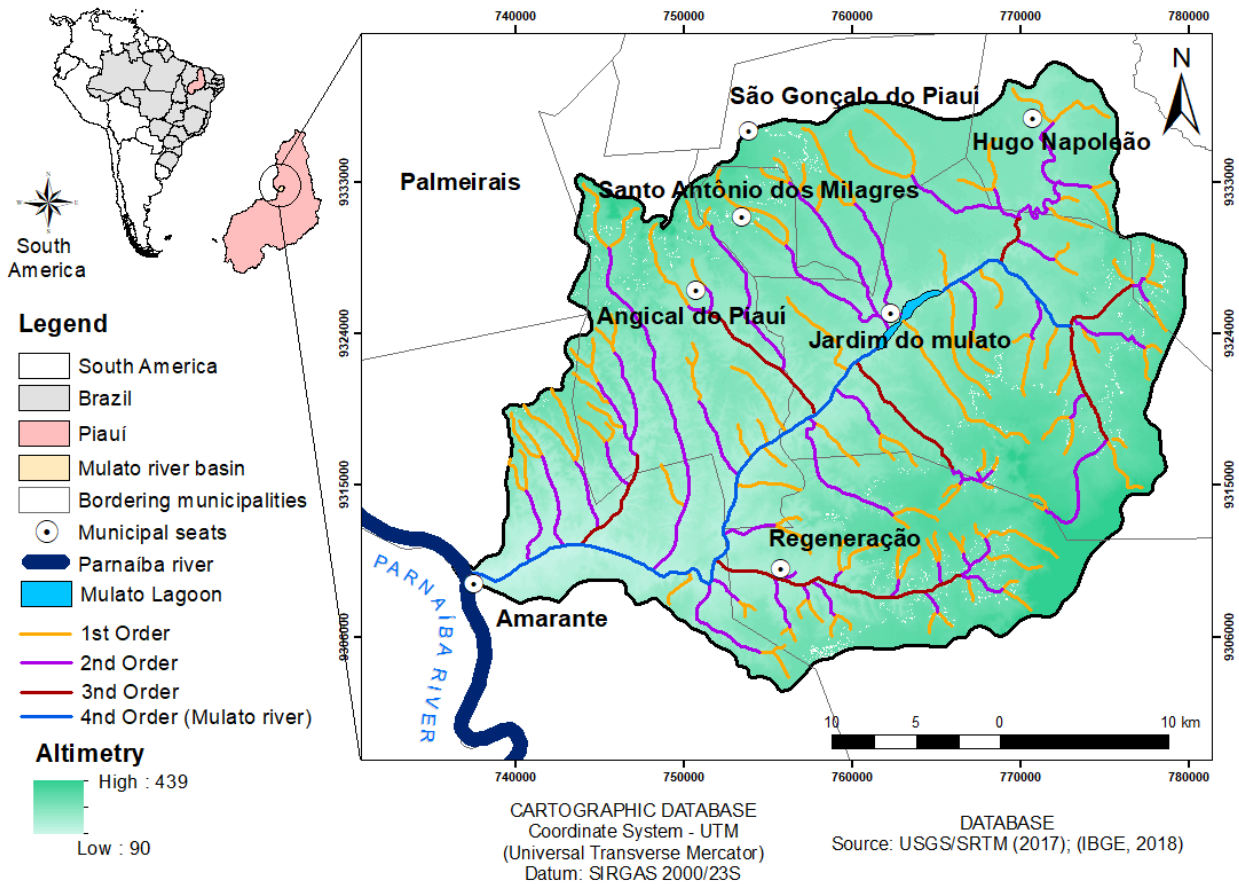


Figure 8. Hydrology of the Mulato River basin, state of Piauí.

Regarding the geographic position within the structural sectors of the Parnaíba hydrographic basin, the MRB is inserted in the group of diffuse basins of the Médio Parnaíba Piauiense.

The drainage network is directly linked to the structural forms of the relief, which function as topographical dividers of the hydrographic basin, together with the lithological structure and fault lineaments. Therefore, it is part of the current domain of the semi-arid region, with an intermittent (dry winter) and perennial (rainy summer) character.

When analyzing in detail the fluvial channels, the Mulato River presents a low degree of sinuosity (1.42), between the straight (1.0) and meandering (1.4) channels. Regarding the general direction, the drainage has a slightly expressive symmetry, with small influences from local geology and geomorphology of structural control on the channel outline, in which it is possible to notice anomalies and distinct flow patterns in some fluvial segments.

In general terms, the MRB presents a subparallel drainage pattern as it is located in areas where there are structural controls which provide the occurrence of regular spacing between surface water flows, being common in areas of parallel faults or regions with topographic lineaments.

From the hierarchical point of view of Strahler (1954), the Mulato River is characterized as a fourth-order channel (Figure 9). According to this author's proposal, first-order channels (without tributaries) are the smallest channels, from its source to its confluence. Second-order channels emerge from the confluence of two first-order channels. When two second-order channels meet, there is a third-order channel. And when this meets another third-order channel, a fourth-order channel appears.

The number of orders of a drainage system is important in the analysis of geological structures, especially fractures. Channels of lower orders are associated with neotectonic movements, while those of higher orders are associated with primitive regional structures (Lima, 2006).

Regarding the drainage density (Dd) parameter, the MRB falls into the low drainage category (0.60 km/km²). This means that the infiltration process prevails, and surface runoff is low. Thus, due to its physical, geological, and topographic attributes, the analyzed area presents difficulties to form new fluvial channels.

The knowledge about soil coverage associated with morphological and morphometric characteristics are essential for understanding the conditions of resistance of the land in face of

erosive processes and/or phenomena. It is necessary to recognize the physical, chemical, and environmental aspects of each type of soil present in the MRB.

According to the classification of EMBRAPA (2013), the MRB is composed of the following soil associations: Neosols, Latosols, and Chernosols (Figure 9).

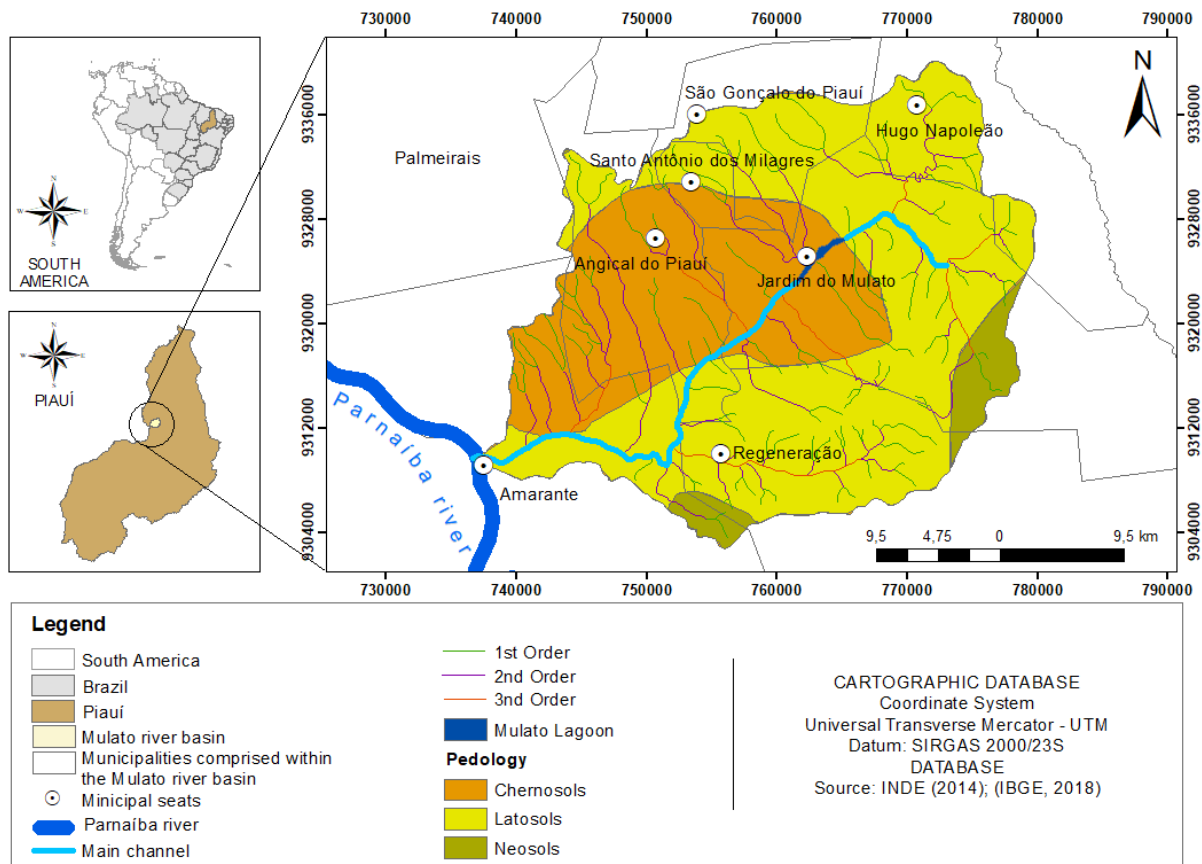


Figure 9. Pedology of the Mulato River basin, state of Piauí.

Dystrophic Litholic Neosols (characteristic of MRB) present base saturation < 50% in most horizons, with low fertility. The fertility is conditioned to the sum of bases and the presence of aluminum in addition to the low levels of phosphorus under natural conditions. They comprise shallow soils, being normally associated with more sloping reliefs, and the limitation to use is related to shallow depths, presence of rock and accentuated slopes. These factors limit root growth, machine use and increase the risk of erosion (EMBRAPA, 2018).

Dystrophic Yellow Latosols are soils of low natural fertility, developed from sandy-clay materials. The medium and sandy texture allows good physical conditions of moisture retention and good permeability, being intensively used for sugarcane crops and pastures. They usually occur in flat or gently undulating relief, being favorable to agricultural mechanization and not favoring erosion. However, compaction problems limit the use of this soil. Rooting is limited in depth because it is dystrophic, and also due to the high cohesion

of aggregates, as the soils are hard or extremely hard in the dry season (EMBRAPA, 2018).

The Orthic Argiluvic Chernosols are soils with a textural B horizon below the chenzemic A horizon. Although formed under highly variable climatic conditions and from different source materials, the development of these soils depends on the combination of conditions that favor the formation and persistence of a superficial horizon rich in organic matter and with a high content of calcium and magnesium, and of 2:1 structure clay minerals (EMBRAPA, 2018).

They have high agricultural potential due to the chemical characteristics mainly associated to the high contents of calcium, magnesium and organic matter, low to medium acidity and high cation exchange capacity related to their mineralogy. In terms of physical characteristics, they vary from shallow to deep soils, and may be susceptible to erosion due to the presence of a clayey horizon - textural gradient. Due to their clayey and very clayey texture, they are normally more porous, presenting good permeability, and

being less susceptible to erosion (EMBRAPA, 2018).

Considering the close relationship that the soil has with the environmental elements,

especially with the vegetation, it was possible to correlate the types of soils present in the MRB with the phytocological units.

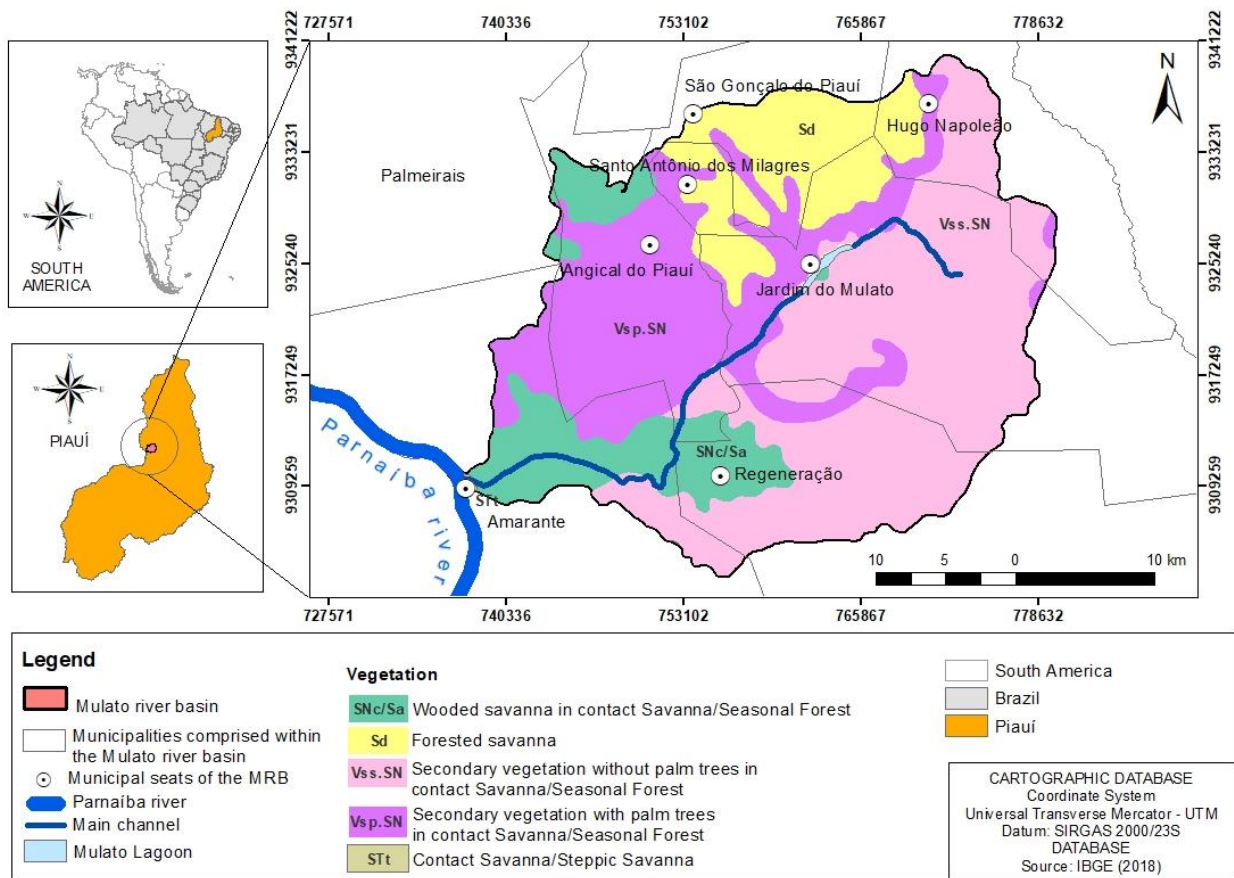


Figure 10. Vegetation present in the Mulato River basin, Piauí state.

In Chernosoils, the presence of secondary vegetation with palm trees in contact with Savanna/Seasonal Forest (Vs p. SN) is predominantly observed; while in Latosols and Neosols, secondary vegetation without palm trees prevails in Savanna/Seasonal Forest (Vs s. SN) (BAPTISTA, 1975; EMBRAPA, 2013). It is also worth noting that MRB is located in an ecotone area (Mata de Cocais, Cerrado and Caatinga), with a predominance in the Cerrado.

The opposite was observed in the research by Sousa e Lima (2021), when performing the environmental diagnosis of the hydrographic basin of the Guaribas River, in the state of Piauí, which, despite also being located in a transition area (Cerrado and Caatinga), is characterized by the predominance of Caatinga. In this context, Batista and Albuquerque (2019) argue that vegetation patterns develop in favorable soil conditions, as vegetation refers to the climax of environmental variables.

From an occupational point of view, the MRB has its origins linked to the more than 300

Indians of the Acoroás and Gueguêses ethnic groups who lived in the region. They were granted fertile lands in the Mulato valley so that they could develop their agricultural activities after the colonization process (IBGE, 2017).

According to the IBGE population census (2020), it is estimated that the inhabitants of the MRB corresponds to a total of 72,541 individuals whose source of income comes mainly from the primary sector (with agriculture, plant extraction, and forestry being the sectors that most generate employment), followed by the tertiary and services sector.

Although no municipality in the MRB has industries in fact, it is necessary to emphasize the importance of the manufacturing of Cachaça Lira (a type of brandy) in the municipality of Amarante for the region's economy, since the production mechanisms of this organic beverage (from sugarcane - *Saccharum officinarum* Roxb.) is aimed not only at the local, regional, and national, but also the international market (Figure 11).



Figure 11. Cachaça Lira Factory, in the municipality of Amarante, Piauí.

The Mulato River intersects this property and played a key role in the process for many years, since the power of water from this drainage was used, at various times, to move the mill, thus involving the conversion of hydraulic into mechanical energy, used in the preparation of this beverage.

Regarding socioeconomic activities, which, as a rule, constitute an essential element for understanding the patterns of organization of the geographic space, a land use and land cover map of the MRB was prepared (Figure 12).

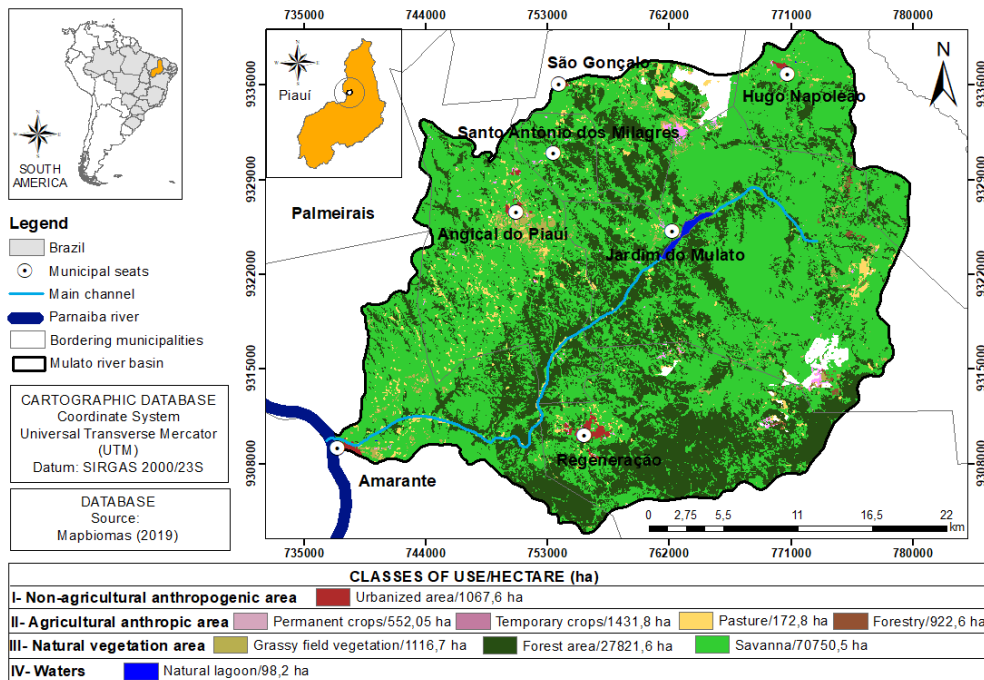


Figure 12. Land use and land cover in the Mulato River basin, state of Piauí.

Through this cartographic product, it was possible to verify the main characteristics of each class of the mapped land, as well as measure the anthropic pressure imposed by economic and social services on environmental sectors.

The first class analyzed consisted of non-agricultural anthropogenic areas (IBGE, 2013). These are located in urbanized sectors, subjected to intensive use, structured by buildings and a road system, in addition to municipal seats with a permanent population center and with urban

functions and own policies, highways, transport services, energy, communications, and industrial and commercial complexes.

The second class was anthropogenic agricultural areas (IBGE, 2013), including all lands used for food production, whether cultivated, fallow or flooded land. In these lands, there are crops cultivated temporarily and/or permanently, pastures, vegetal extraction, forestry, in addition to confirmed agricultural lands.

Among the main subsistence agricultural products from permanent crops, cashew (*Anacardium occidentale* L.), banana (*Musa paradisiaca* L.), and mango (*Mangifera indica* L.) stand out. Among the temporary crops, rice (*Oryza sativa* L.), beans [*Vigna unguiculata* (L.) Walp.], and cassava (*Manihot esculenta* Crantz) stand out.

As for livestock, there is the rearing of chickens, cattle, goats, sheep, and swine. Tambacu/tambatinga (*Colossoma macropomum* x *Piaractus brachypomus*), tambaqui (*Colossoma macropomum* – Cuvier, 1816), and tilapia (*Coptodon rendalli* – Boulenger, 1897) fishery also stand out in five municipalities of the MRB (Amarante, Angical, Jardim do Mulato, Palmeiras, and São Gonçalo do Piauí). Bee honey production is another important economic activity, carried out in the municipalities of Hugo Napoleão and Regeneração (IBGE, 2017).

Regarding plant extraction, there is the removal of carnauba wax (*Copernicia prunifera*

(Mill.) H. E. Moore), wood (charcoal, firewood, and logs), oilseeds (babaçu - *Attalea speciosa*), and forestry (*Eucalyptus* spp. firewood). Forestry is present in the municipalities of Amarante, Hugo Napoleão, Jardim do Mulato, Palmeirais, and Regeneração. Forestry activities with *Eucalyptus* spp. only are intended for vegetal extraction, being the products used as fuel (firewood and charcoal).

Similar data were observed in the research by Oliveira and Aquino (2021), when performing a spatial analysis of the aridity index in the Gurgueia river sub-basin (BHRG), in the state of Piauí. According to the authors, BHRG's main economic activities are subsistence agriculture and extensive livestock, however, this scenario has undergone important changes in the last decade, with the expansion of the grain agricultural frontier, which was also observed in MRB.

According to the Ministry of the Environment (MMA, 2006), subsistence agriculture and extractivism are two essential activities that complement the income of different family nuclei. However, even in the case of areas whose resources are exploited for the survival of the population, this agency warns about the environmental impacts caused by the intense use of the land.

In the upper course of the MRB, it is possible to see some of these impacts (Figure 13), caused by the implementation/expansion of intensive agriculture in the region.

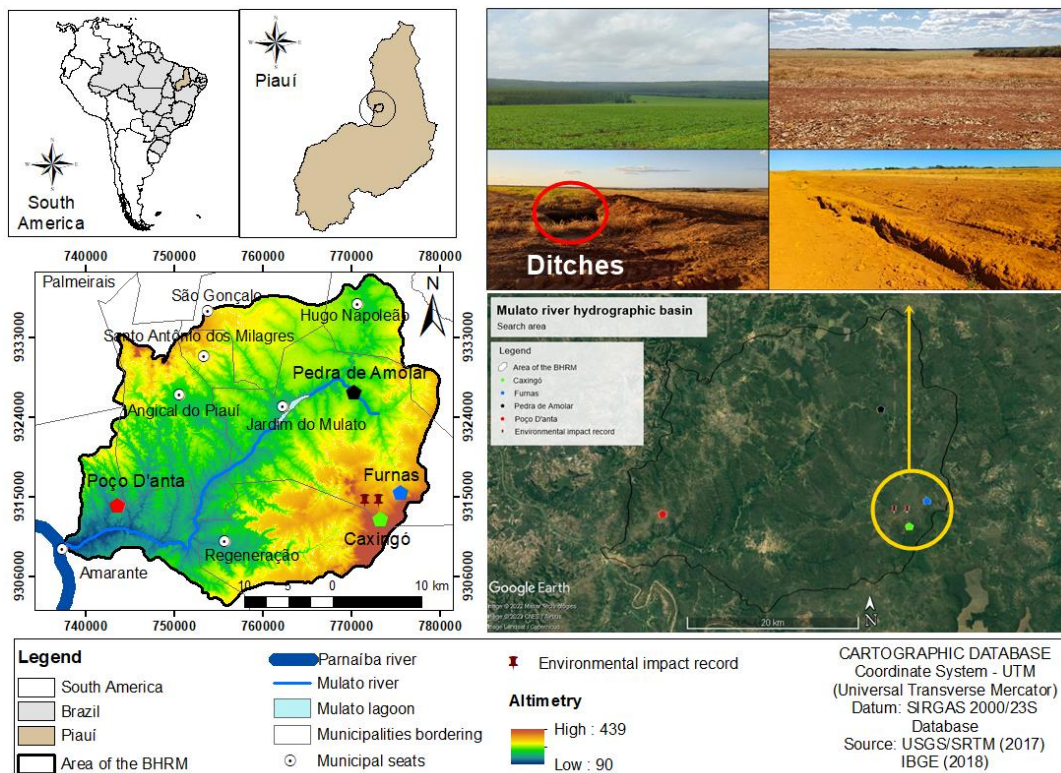


Figure 13. Environmental impacts detected in the Mulato River hydrographic basin, state of Piauí, Brazil.

Among them, the following stand out: reduction/loss of native forest, migration/death of local/regional fauna, ditches opened for water drainage, loss of soil fertility, erosion processes (ravines), and changes in temperature and water availability. Urban expansion and predatory hunting/fishing are also other factors that substantially contribute to environmental degradation. Caselli et al. (2019) obtained similar data when analyzing the land use and land cover in the territory of cocaís.

Areas of natural vegetation were another class observed. This class comprises a set of forest and rural formations, gathering from original primary fields to secondary forest, shrubby, and herbaceous formations (IBGE, 2010). According to the present study, the lands in the low river course tend to present a regeneration into secondary vegetation in the areas destined for subsistence agriculture, since the agricultural activities of rural family farmers are in decline in relation to a few years ago, while the native and secondary vegetation in the high river course tends to be replaced by crops, due to the movement of the agricultural frontier.

Finally, the fourth and last class observed consisted of the analysis of water bodies. These consist of any and all water bodies, whether natural or artificial (rivers, streams, lakes). At the field research stage, it was evident that water resources have been impacted, as they are not being explored with due planning by the populations that use this natural resource, negatively impacting the water quality of the entire area of the river basin. Examples are the dumping of chemical products generated by laundry services (powder soap, bar soap and bleach), disposal of garbage near water courses, and the elimination of riparian vegetation for development of agricultural activities.

Conclusion

The investigation of the elements that compose the natural environment served to know the dynamics of the MRB and its active processes, since human action is, in many cases, the determining factor for the stability/instability of environmental systems.

In this context, it was inferred that the analyzed and interpreted geosystemic characteristics were able to reflect the strengths and weaknesses of the researched natural system.

It was also possible to verify that anthropic actions are not fully consistent with the local reality, which ends up providing and further increasing the impacts of natural elements such as

the soil, vegetation, and water resources that, as a consequence, change the environmental dynamics.

Therefore, research dealing with geoenvironmental characterization becomes increasingly necessary as it consistently collaborate with the in-depth reconnaissance of the area, since this type of study combined with the mapping of physical-natural aspects constitutes an essential tool in strategic environmental assessments, especially in cases of human intervention.

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