

Morphometric characterization of doliniform features in the Araguaia Plain

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Keywords

Mapping
Sinkholes
Karst
Forest fragments

Abstract

The Araguaia Plain has extensive areas of savannah scattered forest fragments similar to circular depressions. These features, in addition to serving as corridors, could be associated with important features such as karsts, closed-water connection structures and ecological-type formations. To identify this relationship and contribute to the understanding of its genesis, this study has as its main objective the morphometric analysis of doliniform functions in the Araguaia Plain. Through the geoenvironmental characterization of the study area; digital facility models – SRTM; interpretation of Sentinel 2-A satellite images from 2019 to 2020; and calculation of morphometric variables: area, perimeters, activity, altitude, length and density, Kernel circularity index. A total of 24,023 doliniform features associated with green/healthy vegetation were identified in a Coverage Area of 114,900 km², Concentrated Majoritariate in the Brazilian municipalities of Lagoa da Confusão -Tocantins; Pium-Tocantins and Cocalinho-Mato Grosso. The features showed circular superiority areas up to 10 km², circular activity indexes at 0.5 and up to 1 and 1.5, indicating a predominance of circular shapes on slopes of 3% in the NE orientation. Based on the results, it can be verified that these features present sinkholes, as they may be under the influence of patterns associated with some processes, denoting in some processes the existence of a covered karst.

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INTRODUCTION

Doliform features are depressions in the terrain with slightly steep slopes in a circular or oval shape caused by the subsidence of the soil. These features can occur in the form of lagoons, sinkholes or delves with or without vegetation. (SCRAGE; UAGODA, 2017).

Doliform forest fragments popularly known as “*ipucas*” or “*impucas*” occur in extensive savannah areas in the Araguaia Plain and represent the main characteristic of the regional landscape (BRASIL, 1981a; MARTINS et al., 2006). However, the origin of these features has not been fully understood in the geomorphological and geological aspect, most studies of these features are associated with phytosociological (disciplinary) or environmental (interdisciplinary) characterization (MANCHOLA et al., 2021).

These features function, in the floodplain, as important ecological corridors for endemic species in the transition area of the Cerrado and Amazonian biomes (ROCHA et al., 2014), a range considered as the largest tropical ecotone in the world (TORELLO-RAVENTOS et al., 2013).

In addition to their ecological importance, these features also occur in the region in the form of dolines, surface forms of the karst system generated by the dissolution of carbonate rocks, but their lithostratigraphic characterization lacks more detailed studies on the local geological profile that corroborate the possible karst genesis of these depressions (HARDT, 2005; MORAIS, 2017). Dolines are considered essential units of exokarst relief, as they function as a connection between surface and underground water flows (FORD; WILLIAMS, 2007). The occurrence of these karst depressions in areas of intense anthropogenic alteration accelerates the dissolution processes and enhances the risks of contamination of aquifers, the collapse of structures or buildings and increased erosion processes (GUTIÉRREZ et al., 2014).

The first geomorphological studies to characterize doliform features along the Araguaia Plain date back to 1981, and were carried out by the RADAMBRASIL project, described in Sheets SB-22, SC-22 and SD-22. In these, closed circular or oval depressions, seasonally flooded (temporary ponds from rainwater), are described on soils of the Gley

Low Humic type with a high content of organic material that favor the emergence of Gallery Forest fragments. Such features are also characterized as patches of vegetation in the savannah landscape of the Cerrado (dity field), formations considered the most representative of the Flood Accumulation Areas - Faa (BRASIL, 1981a; 1981b).

The aforementioned project also highlights the difference between lake systems with circular, oval or straight features in the Fluvial Plain (Apf) that are associated with the water dynamics of the Araguaia River. These lakes are formed by alluvial deposits resulting from vertical accretion processes of sandy sediments in marginal dikes, paleochannels or in abandoned meanders of the main channel and tributaries (BRASIL, 1981a).

These circular depressions in the Araguaia floodplain were also identified in exploratory missions by French and Brazilian researchers in the region of Cocalinho – Mato Grosso - Brazil (southwest of the Plain), near the das Mortes river (a tributary of the Araguaia river). In this region, karst features such as sinkholes were identified in the form of lakes up to 1 km long and 5 m deep, in addition to delves with high speleological potential (SOUBIES; GUYOT, 1995).

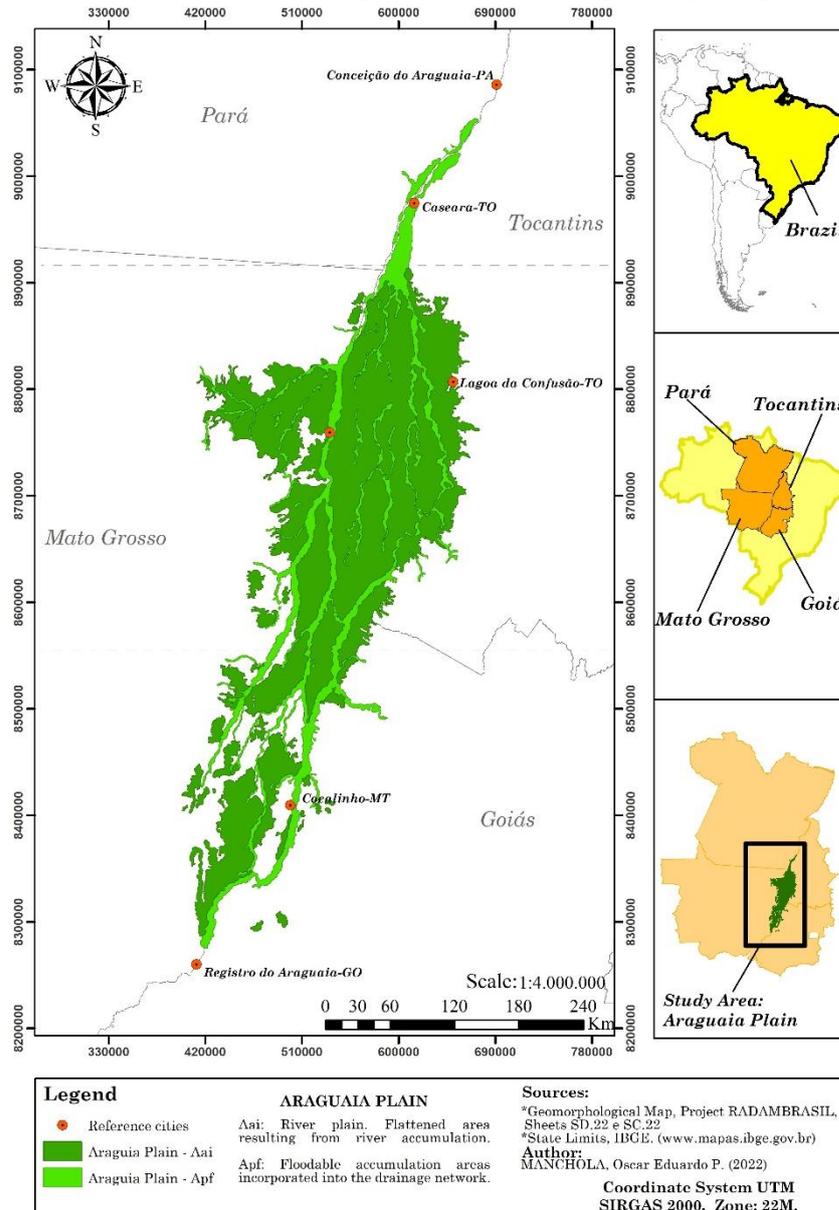
In this way, the identification and subsequent planning of sustainable use of areas prone to the occurrence of sinkholes can prevent potential economic, environmental and social damage. Therefore, it is necessary to map its morphometric characteristics, geological structure and spatial dispersion (WU et al., 2016).

Due to the environmental importance of the Araguaia Plain and based on the hypothesis that the doliform forest formations under the name of *ipuca* and *impuca* are similar to sinkholes in their shape. This work intends to contribute, from the geomorphological point of view, to the understanding of its morphostructure, through the mapping of doliform features and the analysis of the most used morphometric parameters in studies of karst depressions.

Characterization of the study area

The Araguaia Plain is located in the central portion of Brazil, covering parts of the states of Pará, Tocantins, Mato Grosso and Goiás and occupies an area of approximately 64,761 km² (Figure 1).

Figure 1 - Location of the Araguaia Plain and its geomorphological units.



Source: The authors (2023).

Its hydrography is constituted by the Araguaia river basin, considered the main drainage network of the Brazilian savannah, with an average annual flow of 6,420 m³/s, in which the Formoso and Javaés rivers stand out as the main tributaries, with average flows between 110 and 680 m³/s, respectively, in the state of Tocantins; and the das Mortes river in the western portion with an average flow of 899 m³/s in the state of Mato Grosso (LATRUBESSE; TEVAUX, 2002; AQUINO et al., 2009).

The Araguaia basin is characterized by the presence of lakes, ponds and abandoned meanders formed, in part, by the seasonal flooding that occurs in the rainy season from November to May with annual precipitation between 1,400 and 2,200 mm/year

(CARVALHO; ATRUBESSE, 2004; VALENTE; LATRUBESSE, 2012).

The groundwater resources in this area are related to the deposition of Quaternary sediments distributed along the Araguaia Belt. Of these, the most representative corresponds to the porous Araguaia-Bananal aquifer, which represents 85% of the entire Araguaia Plain with flows that vary between 1 and 10 m³/h depending on the rainfall regime (ANA, 2013; CPRM, 2016).

These morphoclimatic characteristics together with the low slope (less than 7%) and reduced surface runoff (predominance of flattened forms) provide the occurrence of extensive zones of fluvial accumulation and sedimentation processes by vertical accretion, favoring the formation of fluvial plains that vary

from 200 to 220 m altitude and slope equal to or less than 5% consisting predominantly of grassy fields on Plinthosols with low water percolation and expressive plinthic horizon (BARBOSA et al., 2011; BAYER; ZANCOPÉ, 2014; EMBRAPA, 2018).

The relief forms of the Araguaia Plain are associated with an agradational system of deposition of Quaternary sediments classified into two dominant geomorphological units, Flood Plains – Fa and Fluvial Plains – Fp (Figure 1).

Floodplains are characterized by converging planes of sandy or clayey sediments with reduced surface runoff that are subject to flooding during the rainy season, which partly favors the emergence of a dispersed lacustrine system with lakes associated with savannah vegetation or closed depressions disassociated from the direct influence of the main channel (BRASIL, 1981a; 1981b).

On the other hand, the Fluvial Plains are formed by the fluvial dynamics of the main channel and, according to Latrubesse and Stevaux (2002), can be subdivided into three geomorphological units:

I – Impeded flow plain: swampy regions occasionally flooded and dammed (back swamp) with slightly undulating topography and distant from the main channel. They feature expressive lakes associated with medium to large vegetation;

II – Paleomeander Plain: Topographically positioned between the impeded flow plain and the plain of islands, it is characterized by intense depositional flood processes, favoring the development of sinuous thalwegs on the banks of the main channel in a spiral, elongated or half-moon lagoons.

III – Plain with added islands/bars: irregular and narrow surface, supported by a sandy platform, positioned parallel to the main channel and characterized by its high capacity for receiving sediments from the Araguaia River.

Regard to the rocky substratum of the Araguaia Plain, this is mostly characterized by Holocene alluvial deposits, which accompany the drainage network, composing a mosaic of Quaternary morphosedimentary structures from the Holocene and Upper Pleistocene, located to the north, between the Amazonian Craton and the Araguaia Belt; and to the south, by extensive Cenozoic covers of the Bananal

Sedimentary Basin (BIZZI et al., 2003; CPRM, 2008).

In the northern sector of the plain, between the cities of Conceição do Araguaia - PA and Caseara - TO, there are outcrops of crystalline and Neoproterozoic rocks, associated with the Couto Magalhães Formation, Tocantins Group, consisting of phyllites, slates, quartz and limestones (IBGE, 2008a).

In the central region, in the segment that includes the entire Bananal Island, the Quaternary formations cover most of the area, extending for approximately 800 km between the cities of Caseara, Tocantins and Registro do Araguaia – Goiás. They present a tectonic alignment parallel to the flow of the Araguaia river in the north-south direction (NS), showing a certain structural control in their orientation (BRASIL, 1981a). Alignments in the NS direction were also identified in the central region of the Plain in lithostructural characterization studies using satellite images, where foliations oriented in this direction are associated with recent formations of “*Neoproterozoic deformation events*” in the Araguaia belt (LEANDRO et al., 2011). Its lithology is constituted predominantly by Cenozoic coverings of sandy sediments belonging to Holocene alluvium and; by sand-clay packages of varied colors with an advanced stage of lateralization of the Bananal Formation (IBGE, 2008b; AQUINO et al., 2009).

In addition to the Cenozoic covers, outcrops of the Couto Magalhães Formation of the Tocantins Group are also identified in some portions of the flood plain, consisting of detritus-laterite covers, limestone intercalations and sericitic quartzites (BRASIL, 1981a). Paixão and Gorayeb, (2014), prospecting mineral deposits in the central sector of the Araguaia Plain, add that the Tocantins Group is characterized by presenting slates, metasilithites, metacorses and metagrauvas, phyllites, metarenites and metalimestones.

In the southern sector, in the segment located on the border between the states of Tocantins and Goiás, the Cenozoic alluvial deposits of the Bananal Basin predominate, consisting mainly of clayey-siltic-sandy and fluvial-lacustrine sediments (LACERDA FILHO et al., 2004). In the extreme southwest, in the higher areas related to a portion of the Araguaia Depression, metavolcanic and metasedimentary rocks from the Neoproterozoic are also found, on silicate, iron and carbonate rocks (SOUSA et al., 2019). In this sense, Lima et al. (2008) point out that the outcrop of carbonate rocks in the south of the Araguaia plain is evidenced by the intense exploitation of limestone in the municipality of

Nova Xavantina, in the state of Mato Grosso indicating the high occurrence of dolomites, calcitic marbles, calcarenites, calcisiltites and clayey metamargas belonging to the Cuiabá Group.

Due to its geographical location, the Araguaia Plain has a high diversity of species, as it is located in a transition zone between the Amazon and Cerrado biomes, providing contact between different ecological communities and the occurrence of endemic species and species adapted to flooding regimes from the seasonal alluvial semideciduous forest, cerradão and savannah park phytophysionomies. This particularity of the region characterizes the region as an important area of environmental preservation, in which the Cantão State Park, the Araguaia National Park, the Araguaia Indigenous Park (Avá-Canoeiro, Iny Karajá, Javaé and Tapirapé peoples) stand out; and the Pimentel Barbosa and Wedezé Indigenous Lands of the Xavante people (ASSIS *et al.*, 2022).

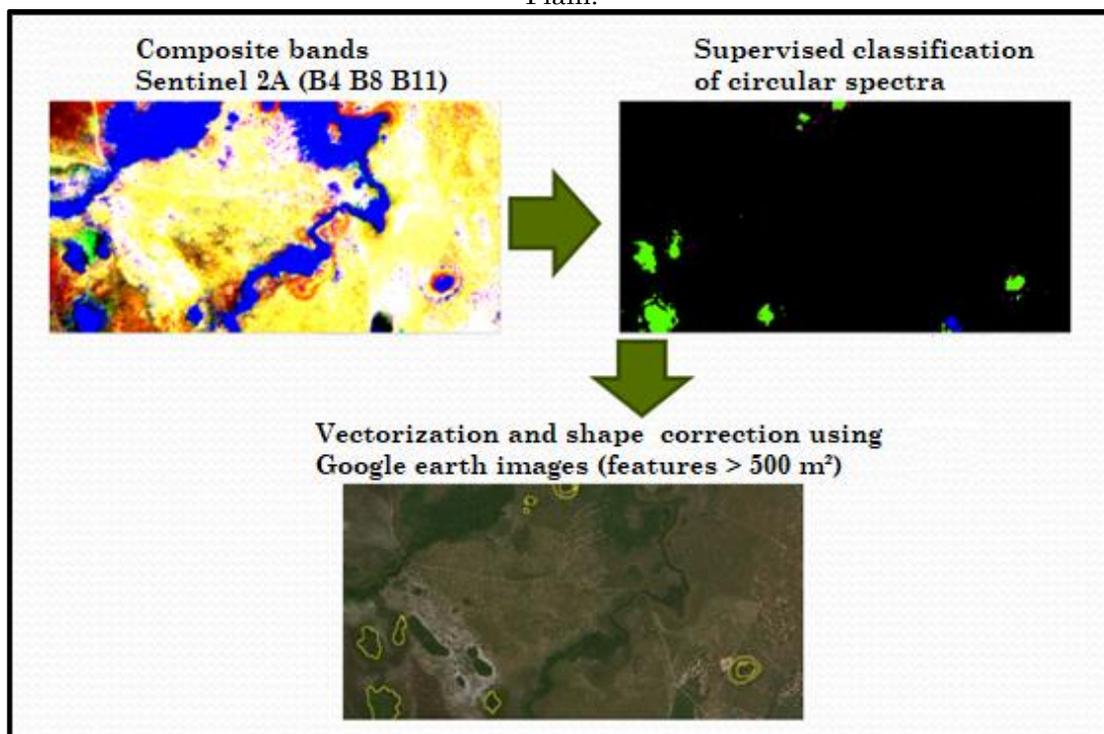
MATERIALS AND METHODS

Methods

To map the doliniform features, a mosaic of Sentinel 2-A satellite images from the period from 2019 to 2020 in the months of July to October with low cloud cover and contemplating the entire inner perimeter of the Araguaia Plain was used. With these images, it was possible to determine the vegetation associated with the depressions through the supervised classification of the composition of the color bands B8 (infrared near 10 m resolution), B11 (shortwave infrared of 20 m resolution) and B4 (red of 10 m resolution).

The identification of doliniform features was carried out considering all circular shapes of the electromagnetic spectrum greater than 500 m² resulting from the combination of bands (B4, B8, B11) and supervised classification associated with bodies of water and healthy green vegetation. The validation of the shape was compared to Google Earth images to ratify the meanings of the shapes (Figure 2).

Figure 2 – Process of identification and classification of doliniform features in the Araguaia Plain.



Source: The authors (2023).

A Digital Terrain Model was generated to observe the altimetry characteristics and confluences of the watercourses in the region through an SRTM image (*Shuttle Radar Topography Mission*) with a resolution of 30 m. Hypsometric, slope and orientation maps of the

slopes were prepared with the objective of analyzing the direction of the slopes and predominant forms that could influence the orientation of the doliniform features.

For the processing of raster images, as well as vector edition, preparation of morphometric

calculations such as width, length, area, perimeter and orientation, the free software QGIS 3.4, Georse 0.5 and R Language and Environment for Statistical Computing 4.1.3 were used.

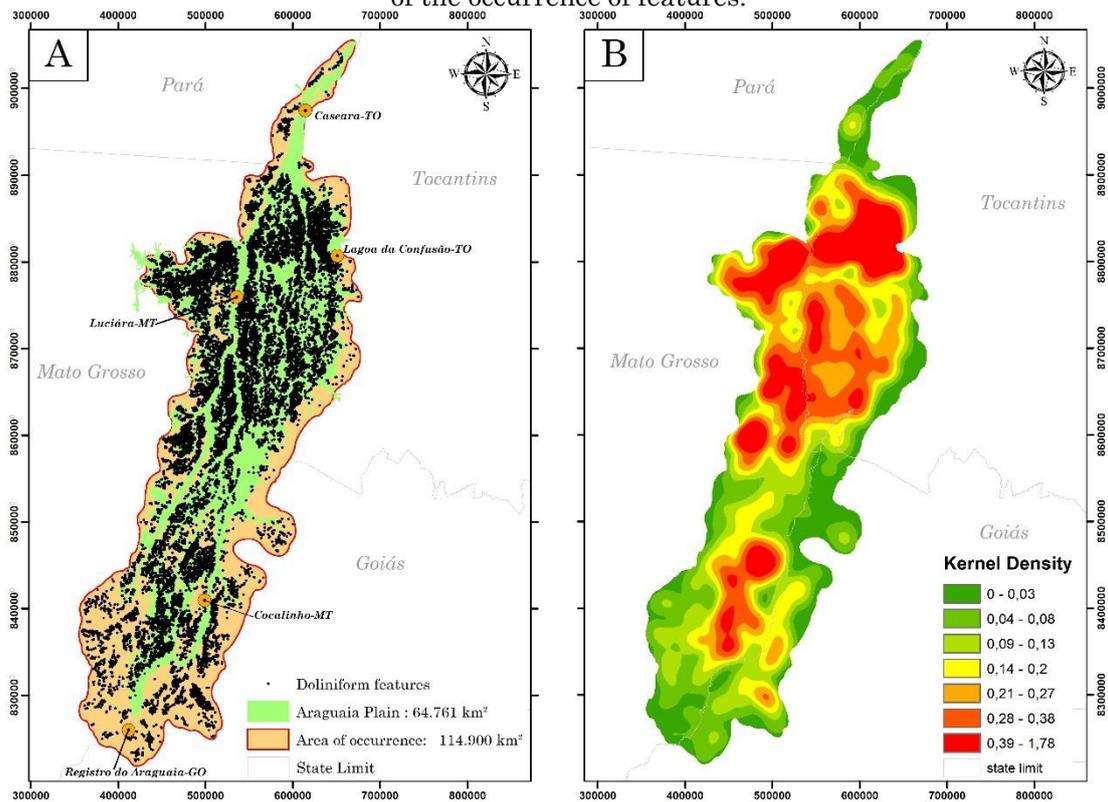
The extraction of the topographic dimensions of the doliniform depressions, in the horizontal profile, was carried out using the *minimum bounding rectangle* method. From these data, the most common coefficients of morphometric analysis of sinkholes were calculated, such as area, perimeter, width (W - width), length (L - length), elongation coefficient (ELG - Elongatedness), circularity index (C - Circularity Index), Nearest Neighbor Distance (DNI), feature orientation, and Kernel Density (BONDESAN et al., 1992; DENIZMAN, 2003; GAO et al., 2005; BASSO et al., 2013).

RESULTS

24,023 doliniform features were identified in an area of occurrence equivalent to 114,900 km². Of these, the features located close to the city of Lagoa da Confusão – Tocantins, Brazil, associated with green/healthy vegetation, presence of water in areas of confluence greater than 800 m² and low slope (Figure 3 A) were validated in the field.

By verifying the density of the doliniform features using the Kernel density map, it was possible to identify that the regions with the highest concentration (hotspots) correspond to the municipalities of Cocalinho, Luciara, Ribeirão Cascalheira, in the state of Mato Grosso; and Lagoa da Confusão and Pium, in the state of Tocantins (Figure 3 B).

Figure 3 – Spatial distribution of doliniform features in the Araguaia Plain. (A) Location of doliniform features in relation to the Araguaia Plain and area of occurrence; (B) Kernel Density Map of the occurrence of features.



Source: The authors (2023).

Of the 24,023 doliniform features identified in the area of occurrence, the main morphometric parameters were extracted and

the highest frequency percentages were calculated (Table 1 and Figure 4).

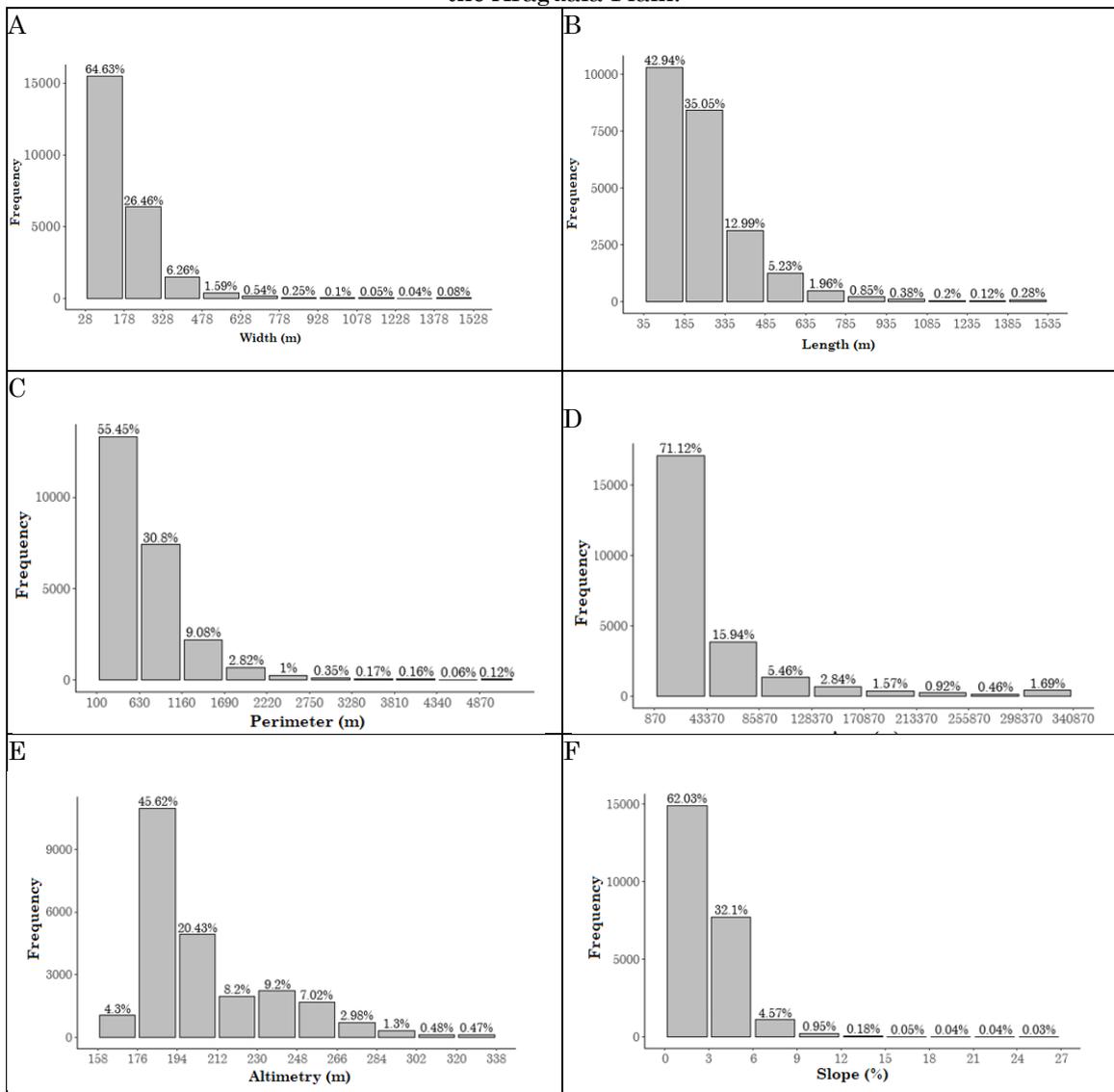
Table 1 – Morphometric parameters of doliniform features in the Araguaia Plain.

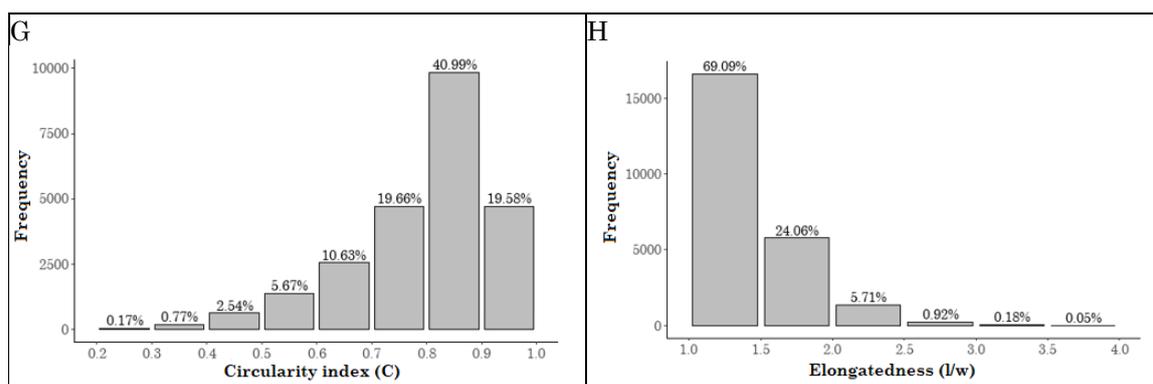
Statistics	Area (m ²)	Perimeter (m)	W (m)	L (m)	DNI	ELG (l/w)	C
Min	864	108.2	29.66	35.01	76.44	1.00	0.20
Q1	11369	402.9	102.72	139.50	321.45	1.20	0.80
Mean	22427	581.2	143.92	206.05	521.52	1.40	0.90
Median	50157	725.0	177.80	255.44	686.27	1.44	0.84
Q3	49537	888.3	214.09	315.45	845.09	1.60	0.90
Max	10038442	11709.9	3389.70	3916.89	12476.36	5.60	1.00

W: Width; **L:** Length; **DNI:** Nearest neighbor distance; **ELG:** Elongation coefficient; **C:** Circularity Index.

Source: The authors (2023).

Figure 4 – Relative frequency of the main morphometric characteristics of the doliniform features in the Araguaia Plain.





Source: The authors (2023).

The mean, minimum and maximum values of the morphometric parameters (Table 1) showed that there is a wide variability in the dimensions of doliniform features, with areas from 864 m² to 10.03 km². The largest ones (above 1 km²) correspond to lake features, such as Lagoa dos Magalhães, 3 km long, located in the municipality of São Felix do Araguaia, state of Mato Grosso; and the 2.5 km long Lagoa da Confusão in the municipality of Lagoa da Confusão, Tocantins.

Most features have an average size of 50,000 m² for the area; 725 m perimeter; and width and length of 177 and 255 m, respectively. These values were also identified in works of morphometric analysis of lacustrine systems in the mid-Araguaia, during the dry period, and may increase in size by up to 100% during the flood period, depending on the degree of connectivity with the main channel and the drainage density of the channels from the plain (MORAIS et al., 2005).

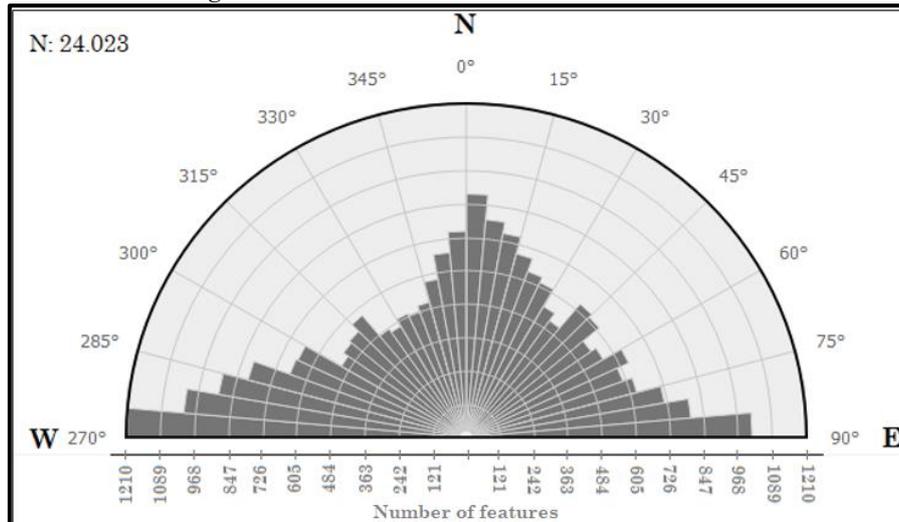
With regard to shape, it was observed that more than 60% of the identified doliniform features have dimensions of less than 43,370 m² with perimeters from 100 to 1000 meters (Figure 4-C), axes (width and length) between 178 m

(Figure 4-A) and 335 m (Figure 4-B). These features are mostly located in regions with slopes between 0 and 3% (Figure 4 F) and at altitudes between 176 and 212 m (Figure 4 E) with circularity indices between 0.8 and 1 (Figure 4 G); and elongations between 1 and 1.5 (Figure 4H). Shapes with roundness and elongation indices close to 1 indicate, according to Basso et al., (2013) and Denizman (2003), predominantly circular or oval features.

The average length of 206.42 m, circularity indices greater than 0.5; predominance of circular shapes (95.15% of features), were also identified in studies of morphometric analysis of doliniform features in the region of Lagoa da Confusão - TO, corroborating the predominance of circular or oval shapes identified in the Araguaia Plain (NASCIMENTO; MORAIS, 2012).

The orientation of all identified doliniform features showed a high variation of directions, of which the East-West orientation (Figure 5) showed greater proportions, indicating a tendency for some features to be aligned with the same surface flow direction of the Araguaia tributaries.

Figure 5 - Orientation of doliniform features.

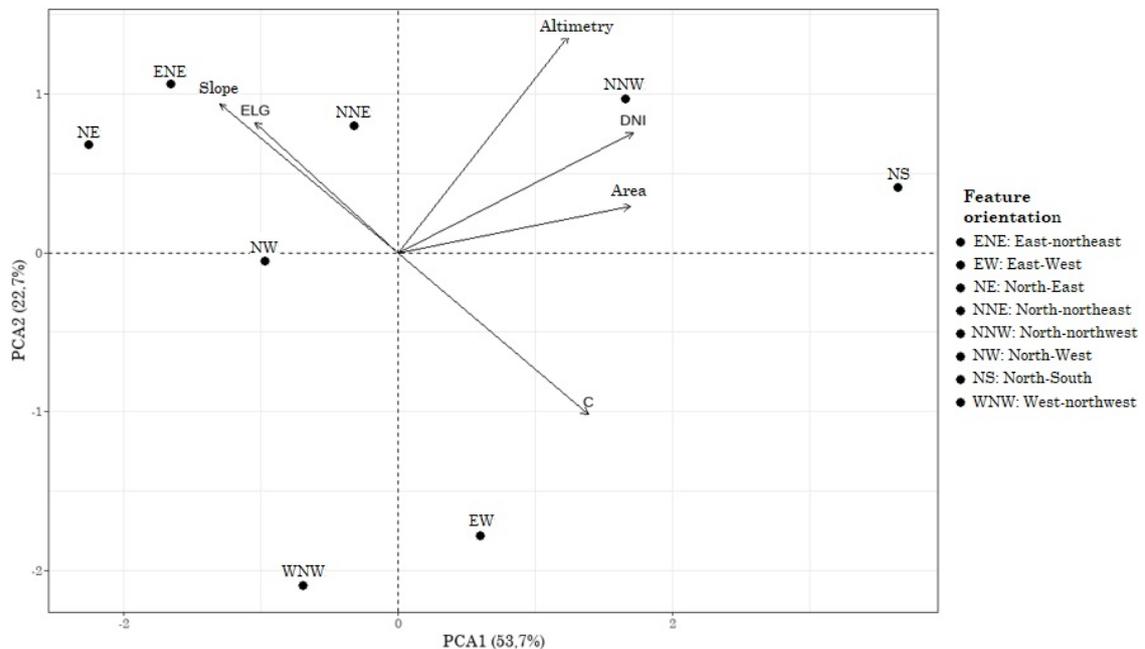


Source: The authors (2023).

Regarding the spatial arrangement of the features, it was observed that their dispersion presents a random distribution throughout the study area (Figure 1), with distances varying between 76.44 m and 1,2476.36 m (Table 1). By identifying the random distribution and the distance from the nearest neighbor (DNI), the spatial distribution index (R) was estimated

through the average observed distance (686.27 m); the expected average distance (820.94 m) and area of the Araguaia Plain (64,761 km²), corresponding to 0.83, which represents, according to GAO et al. (2005), a tendency towards grouping (Clustering) of the features identified in the Araguaia Plain.

Figure 6 – Principal component analysis (PCA) of the main morphometric variables identified for the doliniform features of the Araguaia Plain (area, slope, elevation, distance from the nearest neighbor (DNI), elongation coefficient (ELG); circularity index (C), Orientation of features).



Source: The authors (2023).

The principal component analysis represented 76.4% of the morphometric data of the doliniform features, showing a high correlation between the slope and elongation coefficient (ELG) variables associated with

orientations: northeast (NNE); east-northeast (ENE) and north-northeast (NNE), demonstrating a possible tendency for elongated or oval features to be under great influence of the topographical or structural conditions of the

terrain, predominantly oriented in the northeast (NE) direction.

On the other hand, an inverse correlation was observed between the slope variable and the circularity index (C), corroborating the influence of the terrain on the occurrence of circular doliniform shapes associated with low slopes, mostly oriented in the East-West direction (EW), predominant orientation also identified in Figure 5, indicating a possible tendency for most of the circular shapes to be aligned in the same direction as the surface flows of the main channel of the Araguaia River.

It was observed, therefore, that there was a predominance of circular or oval features with areas from 864 to 10,038,442 m², oriented in the NE direction for the oval features and EW direction for the circular features. These directions, based on the results obtained in the PCA, may be associated with the convergence of surface flows to the main channel (EW) or by structural controls in the NE direction, related to the position of the Tocantins Group.

DISCUSSION

The hypotheses about the karst origin of the features identified in Cocalinho - MT was corroborated years later by Hardt (2005) through the geomorphological characterization of the karst relief of the Serra de Calcário, in floodplain areas of the plain. In this study, carbonate outcrops were identified in the form of limestone hills, karst towers, caves, springs, sinkholes and dissolution and collapse uvalas with kilometric dimensions and depths of up to 5 m. Most of these features were identified parallel to Serra de Calcário and tectonically conditioned by faults in the WSW-ENE direction.

This orientation was also verified in this study, through principal component analysis (PCA), as well as in works of morphometric analysis of doliniform features in the municipality of Lagoa da Confusão, Tocantins, where average lengths of 206.42 m were identified; density of 2.25 features per km² and tendency of the longest axis in the NE-SW direction (NASCIMENTO; MORAIS, 2012). The Araguaia National Park Management Plan also shows a large number of circular depressions in the form of lagoons aligned parallel to the faults, in the vicinity of the Bananal Plain and the Formoso river, suggesting a probable structural control for this area (IBAMA, 2001).

Tectonic controls and the parallelism of the doliniform features with the faults and

fractures, oriented in the ENE direction, could give evidence of the possible karst origin of the doliniform features. However, some studies in the Araguaia Plain associate its genesis either to the formation of lacustrine systems by dissolution or to natural processes of recomposition of native vegetation.

The association of doline-type karst forms with forest formations is evidenced in the environmental diagnosis proposed by Martins et al. (2002), which characterizes the forest fragments called “*ipucas*”, located in the Flood Plain, in the Tocantins region, in the municipality of Lagoa da Confusão. In the Mato Grosso portion, these forest fragments are also identified in the form of dolines, however, called “*impucas*” (MARIMON et al., 2012).

The “*ipucas*” are vegetation fragments with a predominance of shrubby and subshrubby species and some medium-sized tree individuals adapted to flood flows. (*Calophyllum brasiliense*, *Vochysia* sp, and *Sclerolobium* sp.), classified as Seasonal Alluvial Deciduous Forests and located on depressions in shallow soils with a high content of organic matter and fine materials such as silt and clay under the high influence of the water table. These forest formations have areas between 50,000 and 2,460,000 m² and circularity indices between 0.1 and 0.85 (MARTINS et al., 2002).

It should be noted that these forest fragments called “*ipucas*” or “*impucas*” are of vital importance in the context of the ecology of the Araguaia landscape, as they function both as temporary habitats for endemic species and as ecological corridors for amphibians and birds in the Cerrado and Amazon ecosystems (PINHEIRO; DORNA, 2009; ROCHA et al., 2014; KURZATKOWSKI et al., 2015; LOPES et al., 2017).

From a geomorphological point of view, not all “*ipucas*” or “*impucas*” should be associated with sinkhole-type karst features, as such forest fragments also occur in abandoned meanders and paleochannels of the Araguaia Fluvial Plain, a fact proven by the highly elongated, sinuous and rectilinear; as well as circularity indices below 0.5.

The proposed genesis of these forest formations (*ipucas*), in a circular shape, was related to subsidence processes in hydromorphic soils, seasonally saturated such as Plinthosols and Gleysols with pH between 4.1 and 6.8 and high amount of organic matter in their interior. The subsidence of these features was theoretically associated with two processes: the lowering of the water table and the transformation of clayey-sandy sediments by ferrololysis; and the formation of dolines by karst

processes of dissolution of limestones of the Tocantins Group (MARTINS *et al.*, 2006).

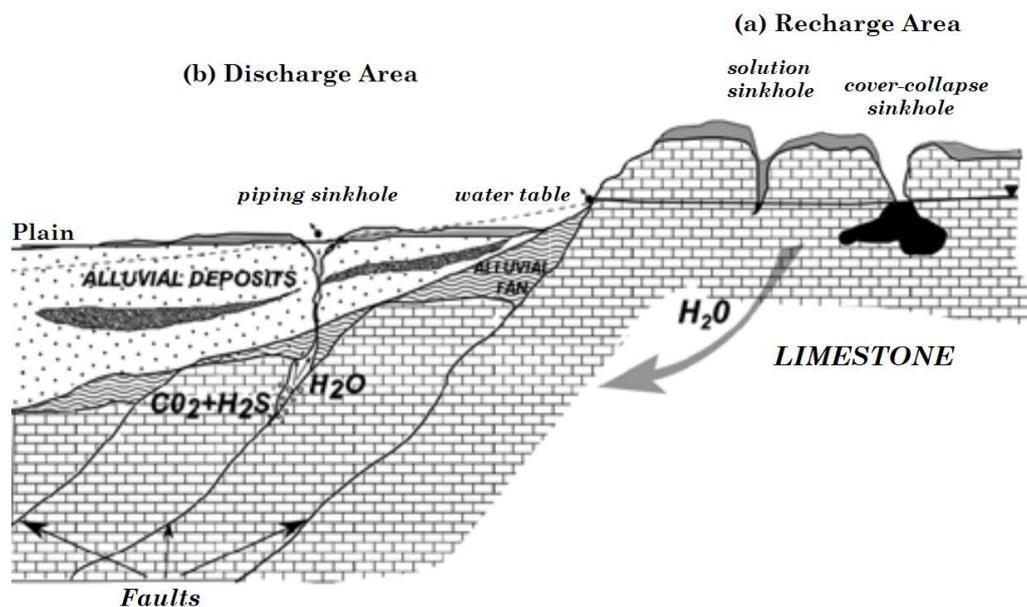
The proposal for the genesis of forest formations associated with sinkholes based on karst processes can be complemented based on evidence of karst structures identified in the municipality of Lagoa da Confusão, Tocantins, where limestone-dolomitic outcrops of the Tocantins Group, in the form of 30 m high mogotes, have karrens, sinkholes and a complex system of conduits and galleries identified in the Casa de Pedra cave (PONTALTI; MORAIS, 2010).

From another perspective, the genesis of these doliniform depressions in the form of lakes, located in the municipality of Aruanã (northwest of Goiás) is described through processes of mobilization of fine sediments on the surface, causing the detachment of the lateritic crust on the saprolite of the crystalline rock (CARVALHO; LATRUBESSE, 2008). This

process would generate small and rounded lacustrine features, conditioned by a set of fractures that allow the alignment in the NE-SW and NW-SE directions, revealing an evident tectonic control over the features in the stage of coalescence (VIEIRA, 2002).

However, this process may also be related to the formation of karst depressions when considering: the high seasonal oscillation of the water table throughout the year on the carbonate substrate underlying the Holocene sedimentary layer of the Araguaia Plain. In this regard, Caramanna *et al.* (2008) identified dissolution processes in circular karst depressions of the deep piping type in Italian plains characterized by a thick Quaternary alluvial lateritic cover (impermeable or semi-permeable) of up to 100 m, superimposed on an underlying carbonate substrate in the widespread presence of faults (Figure 7).

Figure 7 - Generation model of doliniform features in flat areas with carbonate substrate underlying alluvial sedimentary deposits. (a) recharge area with outcrops of carbonate rocks. (b) discharge area, where deep piping sinkholes can occur over plains with alluvial deposits.



Source: Adapted from Cardarelli *et al.* (2013).

This phenomenon of deep piping occurs when the drastic oscillation of the water table, due to periods of heavy rains and prolonged droughts, increases the rise of groundwater over the carbonaceous (faulted) rock, creating small cavities and conduits by dissolution. These conduits increase the ascending endorheic flow, allowing water erosion of cohesive debris from the upper layers by physical-chemical processes, with the removal of less resistant granules occurring, and dissolution, in an acid medium, acts on the cement located in the intergranular

contacts of the siliciclastic rock, changing its consistency (sandstone), favoring the downward displacement of non-cohesive sediments (hourglass effect), forming conical and circular depressions on the surface in the fault plane (CARAMANNA *et al.*, 2008; CARDARELLI *et al.*, 2013; VERESS, 2020).

The occurrence of the possible carbonate substrate underlying the alluvial deposits of the Araguaia Plain was described through geophysical studies with vertical electrical soundings-SEV, at depths of up to 42.6 m, in the

region of Lagoa da Confusão, Tocantins. In this location, upper saturated (clay) and semi-saturated (sand-clay) sedimentary layers superimposed on a possible carbonate layer with resistivity values associated with limestone dolomites were identified (PEREIRA; MORAIS, 2012).

FINAL REMARKS

By mapping the doliniform features, it was possible to observe that the area of occurrence of these features exceeds the geological unit of the floodplain, covering an area of 114,900 km², equivalent to 46.6% more than the initially designated area.

The highest concentrations of features, identified through the Kernel density map, are located in the municipalities of Cocalinho – Mato Grosso, Luciara – Mato Grosso, Ribeirão Cascalheira – Mato Grosso, Lagoa da Confusão – Tocantins and Pium – TO.

With regard to the generating agent of the doliniform features, there are some indications pointing to the formation of depressions with forest formations resulting from the dissolution of covered karst, such as: the occurrence of a quaternary depositional system predominantly flattened and strongly modeled by the high seasonal water load; limestone outcrops of the Tocantins Group in the area where the features occur; structural control indicated by the NE directions of the features and; predominance of circular shapes covered by healthy green vegetation with the constant presence of water. However, to corroborate these hypotheses, geophysical studies capable of identifying the underlying lithologies at depths greater than 50 m or geological soundings that contribute to the understanding of the genesis of these features are necessary.

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AUTHORS CONTRIBUTION

Oscar Eduardo Paez Manchola conceived the study, wrote the text, collected and analyzed the data. Fernando de Moraes conceived the study, guided and revised the text.



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