Landscape analysis to identify landforms from images generated by lidar technologies

https://doi.org/10.56238/sevened2024.018-032

Urandir Fernandes de Oliveira[1], Fernanda Maria de Lima[2], Robson Leite[3], Saulo Ivan Nery[4] and Fernando Silveira de Oliveira[5]

ABSTRACT

This article presents the analysis of the landscape of peculiar reliefs called "chess", located in the north of the municipality of Apiácas, in the state of Mato Grosso. It is a residual relief from denudational processes typical of the Amazon Craton, identified in the region of the lower course of the Juruena and Teles Pires rivers. The intention is to contribute to the local geomorphological knowledge about the differentiation between drainage patterns and the rectilinear cuts located on the residual plateau of the Apiacás and Sucunduri. The images obtained with LiDAR and the geological and geomorphological information of the region were compared based on secondary data from IBGE surveys and other surveys. Based on the delimitation of sub-basins and micro-basins and observations about the surface circulation of water, it was possible to better understand the local relief. Peculiar structures were identified in the relief and indications that differentiate the drainage pattern with the sections identified in a "checkerboard" format.

Keywords: LiDAR, Drainage patterns, Landforms, Chess, Apiacás, MT, Amazon.

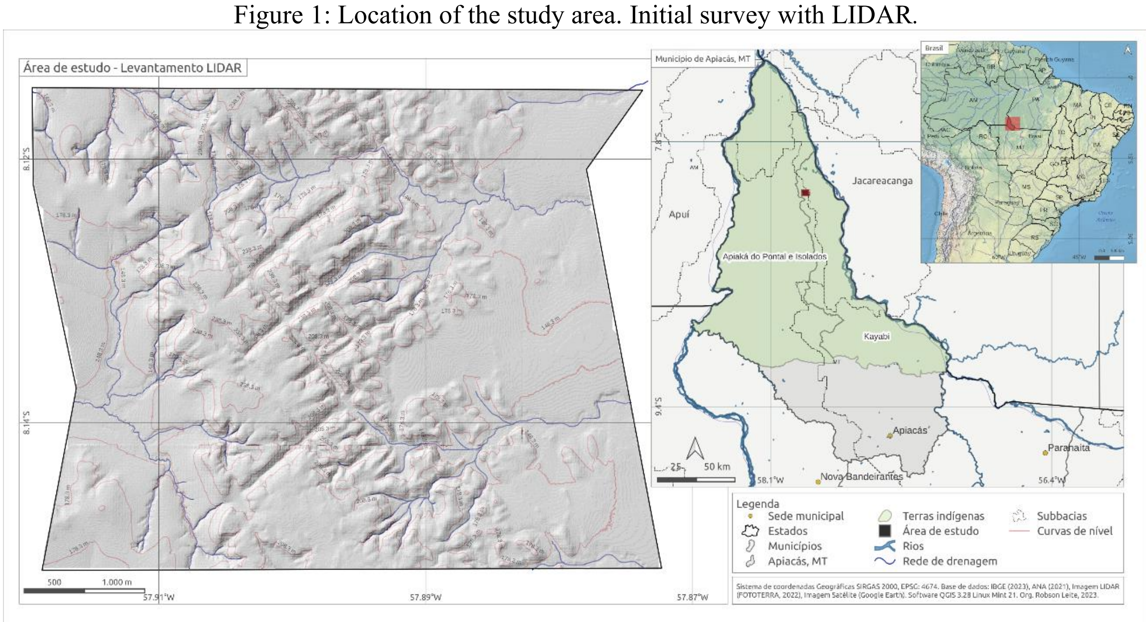
[1] President of the Dakila Civil Association
E-mail: urandirf2028@gmail.com
[2] Bachelor's degree in Mechanical Engineering with emphasis in Mechatronics from PUC/MG
E-mail: fernanda.lima@dakila.com.br
[3] Master in Physical Geography FFLCH/USP
E-mail: robsonleite.pro@gmail.com
[4] Master in Rural Studies/UFVJM
E-mail: saulo.nery@dakila.com.br-mail
[5] GlobalMapper Software Technician for Geoprocessing by Sigma Profissões
E-mail: fernando.andreazza@dakila.com.br

INTRODUCTION

The study area in question is located in the municipality of Apiacás, in the extreme north of the state of Mato Grosso, on the border with the states of Amazonas and Pará, at the confluence of the Juruena (to the west) and the Teles Pires (to the east) rivers. It is an area of high Amazonian vegetation density located in the northern portion of the Kayabi indigenous land[6]; close to the border with the Apyacá do Pontal and Isolados indigenous land[7]. As it is an inhospitable area, it was decided to analyze data collected by remote technologies that allow a greater understanding of the landscape without the need to travel by land to the site.

Data collection was done in an area of two thousand hectares using *LiDAR technology*[8], allowing a detailed survey with the production of a digital model of the terrain capable of differentiating the forms contained in the landscape, thus making it possible to identify peculiar forms in the local relief in relation, above all, in the identification of differences and similarities in drainage patterns. The relief of the studied area is in a "checkerboard" format, with the outline of "*grids*" (orthogonal lines, perpendicular to each other) that are not directly related to any drainage pattern (Figure 1). The number of scientific studies using *LIDAR* has been growing, especially in geomorphological analyses (ARAUJO et al, 2022), which can provide new interpretations, refinement of research carried out so far, and new details about the modeling of environmental systems.

Figure 1: Location of the study area. Initial survey with LIDAR.



6 Land traditionally occupied by the Kaiabi ethnic group, regularized and located in the municipalities of Apiacás in the state of Mato Grosso and Jacareacanga in the state of Pará.

7 Indigenous land traditionally occupied by the Apiaká ethnic group and isolated peoples, delimited and located in the municipality of Apiacás, state of Mato Grosso.

8 *LiDAR (Light Detection and Ranging)*, laser scanning to obtain detailed topographic information, even on mountainous and densely forested surfaces, greatly increasing the capacity for data collection.

METHODS AND MATERIALS

For this study, we used the Digital Elevation Model (DM) from the remote sensing technology with the LiDAR (*Light Detection and Ranging)* light detection and ranging system rendered in *the Global Mapper software*, version 23.1. It is a point cloud MDE image with 145 layers and a resolution of 8 pulses per square meter. We do not use Digital Surface Modeling (MDS) because of the vegetation density at the site. The final maps were prepared in the QGIS 3.28 software, adopting the SRC (Coordinate Reference System) SIRGAS 2000, Zone UTM 21S, EPSG 31981.

Geographic Information Systems (GIS) are used for the analysis and planning of landscapes and the environment (LANG and BLASCHKE, 2009). For the composition of the landscape studies, a survey of secondary data from geological and geomorphological research developed in the region was used. The presence of some geological faults and structural surface lineament to the north and northwest of the studied area were identified on a regional scale, according to data from IBGE (2017) and ANM (2014); we also sought to identify the natural drainage pattern based on the LIDAR images, comparing them with the maps and topographic maps available on the Brazilian Army website (BDGEx, 2022).

We compared the rectilinear shapes identified in the relief with the local drainage pattern (CHRISTOFOLETTI, 1980; SUGUIO and BIGARELLA, 1990). Data regarding the depth, width and extension of the cuts were also collected, which were organized and analyzed here.

RESULTS AND DISCUSSIONS

According to the studies consulted (STUDART et al., 2006; PIEROSAN et al., 2019; UHLEIN et al., 2015, LACERDA FILHO et al., 2004) a closer geological fault was identified, the *Cachimbo Graben*[9] , located more than one hundred kilometers in a straight line from the study area, characterized by being a megastructure with a NW-SE direction. With a geological base on rocks from the Beneficent Group, from the Igarapé Ipixuna sedimentary formation, composed of sandstone quartz (CPRM, 2014), the Apiacás and Surunduri plateau is characterized by a set of mountains that form a watershed of the tributaries of the Teles Pires (to the east) and Juruena (to the west) rivers, with reliefs dissected into ridges, hills and spikes with flattened tops, embedded valleys and ravine slopes, comprising the geomorphological region of the residual Plateaus of the Southern Amazon (IBGE, 2017).

The hot and humid equatorial climate predominates in this region. The Brazilian Amazon is one of the most humid forests in the world and the action of water is a primary factor for the

9 According to Guerra and Guerra (2006, p. 286), *Graben* or fossa refers to a depression elongated by a series of steps produced by parallel faults.

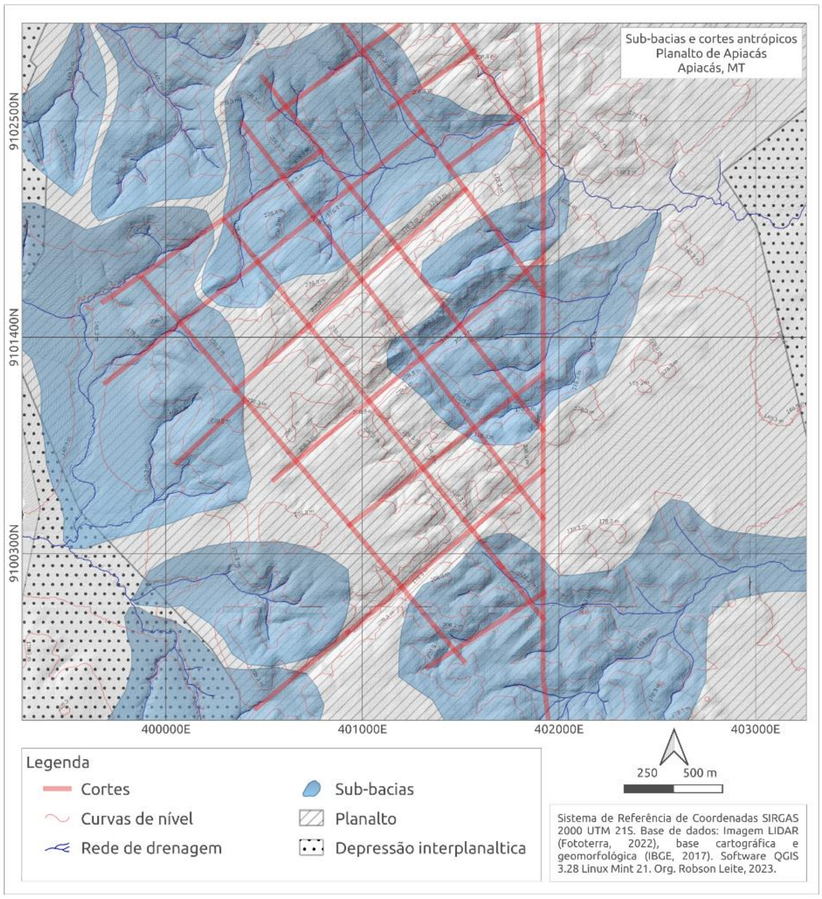
processes of construction and alteration of the relief, considering that the study area has a high level of precipitation. With annual rainfall of 2,750 mm, maximum rainfall occurs in January, February and March; and the minimum rainfall occurs from June to July. The average annual temperature is 24ºC, with a maximum of 40ºC. All this precipitation favors the formation of large rivers and a dense drainage network.

It is noted that the natural pattern of the drainage network on the slopes of the plateau, printed in dendritic form, occurs mainly in the lower parts of the relief to the west. At the top of the plateau, to the east, in the higher areas of the area's relief, we identified rectilinear cuts that are different from the river valleys sculpted by natural erosion and that may be associated with other processes. In official maps and charts (IBGE, 2017; ANA, 2021; BDGEx, 2022) no type of drainage consistent with such cuts or that the drainage network is classified as rectangular or parallel was not identified. Drainage channels were identified, most likely formed from the surface runoff of rainwater, located at the bases of the identified cuts.

Evidently, the formation of rainwater runoff sites was formed at the base of the cuts, however, not all of them have these marks. Some marks are close to the drainage headwaters. Therefore, the cuts in the terrain contributed to increase the collection of rainwater from the highest parts of the relief.

To differentiate the cuts in the drainage network, it was decided to delimit some sub-basins and micro-basins (GOMES, BIANCHI, OLIVEIRA, 2021) and that the watershed is an important geomorphological unit to understand drainage patterns and water flow (LEOPOLD, WOLMAN, MILLER, 1964; CHORLEY, 1969; CHRISTOFOLETTI, 1980). This delimitation considered the watersheds between the tributary rivers and the main rivers, which demonstrated that certain cuts are not directly associated with the basins and the dendritic drainage pattern (Figure 2).

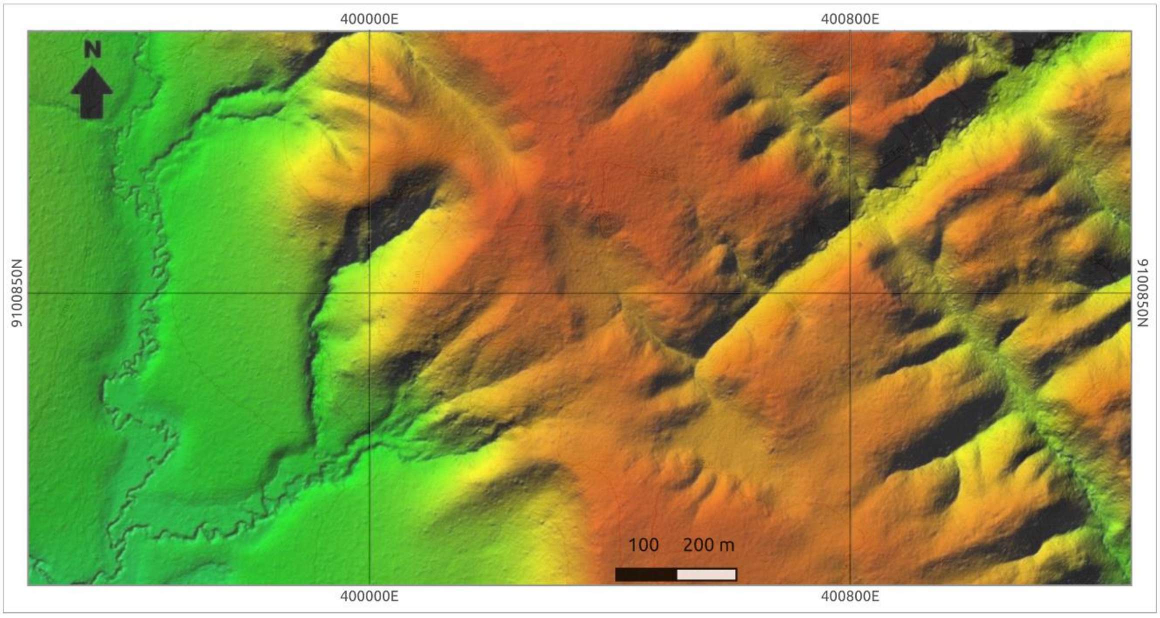
Figure 2: Delimitation of sub- and micro-basins and identification of peculiar sections in the relief. The cuts do not follow the dendritic drainage pattern and the basins. Map at 1:20,000 scale.



By delimiting some drainage sub-basins that make up the residual plateau based on the topography of the relief, it is possible to perceive that the cuts in the terrain are not limited to the domain of the drainage basins that form the headwaters of watercourses in the area. It is also noted that the cuts are not topographically confused with the river valleys, as cuts were identified that exceed the limits of two or more drainage headwaters that form the sub- and micro-basins.

The Juruena River, to the west, and the Teles Pires River, to the east, serve as the local base level for the tributary rivers that originate on the residual plateau. The east side of the plateau features more eroded slopes and a vast plain on the banks of the Teles Pires River. The west side of the plateau, in turn, has steeper and more conserved slopes (Figure 3). This points to the process of regressive erosion, which is the "work of wearing down the bottom of the riverbed being done from downstream to upstream" (GUERRA and GUERRA, 2006), but that to the east this process is more intense. For Ross (1991) some plateaus with flat or flattened surfaces are found on the edges of sedimentary basins sculpted by circumdenodational processes frequently found in the Amazon, and these terraces are associated with regressive erosion in drainage headwaters or parallel retreat of slopes.

Figure 3: LiDAR image detail. Difference between rectilinear formations to the east (in yellow and red), over the residual plateau, and the river valleys and their respective drainage pattern to the west (in green).



From these cuts, it can be seen that there is a certain average depth that was identified. In a preliminary analysis, we noticed that the cut apparently deepens in the top areas and becomes shallower in the middle and lower portion of the slope. There is a main cut in the eastern portion that extends for about eleven kilometers in a north/south direction. We use this section as a reference for the structure as a whole, and as a way to understand the arrangement of the other perpendicular sections.

Data were collected that indicate the sinuosity of the cuts. Thus, it was identified that of the total of twenty-nine cuts that form this "checkerboard" in the relief, only four presented sinuosity and the remaining twenty-five are rectilinear. The classification by sinuosity was performed in the *Global Mapper software*. Fifteen sections had a southwest/northeast direction, eight had a northwest/southeast direction. Six sections had a north/south direction, and another six had an east/west direction.

Figure 4: Table with collection of measurements of the cuts.

Corte no Terreno	Distância	Rumo	Sentido	Sinuosidade	Medidas Altitudes a cada 500m						
Principal	11.153 km	176° 55' 07.193"	Norte/Sul	10.201.586	147.40 m	145.97 m	134.58 m	134.52 m	142.17 m	149.09 m	160.88 m
1	1.538 km	64° 44' 40.174"	sudoeste/nordeste	1	135.24 m	173.39 m	193.76 m	189.48 m			
2	1.159 km	55° 38' 16.567"	Sudoeste/Nordeste	1	160.21 m	151.37m	194.29 m				
3	1.646 km	54° 09' 40.695"	Sudoeste/nordeste	1	142.58 m	159.98 m	177.85 m	208.07 m			
4	1.35 km	55° 22' 07.431"	Sudoeste/nordeste	1	171.58 m	177.95 m	155.94 m	148.81 m			
5	875.87 m	57° 35' 39.253"	sudoeste/nordeste	1	155.49 m	202.69m	165.73				
6	2.059 km	51° 36' 34.398"	Sudoeste/Nordeste	1	160.52 m	159.64 m	194.36 m	223.45 m	150.95 m		
7	585.53 m	54° 30' 51.757"	sudoeste/nordeste	1	171.22 m	151.04					
8	472.45 m	47° 11' 27.067"	sudoeste/nordeste	1	241.52 m	151.85					
9	1.558 km	49° 02' 12.497"	Sudoeste/nordeste	1	156.33m	178.66 m	205.77 m	239.79 m			
10	1.666 km	50° 34' 04.814"	Sudoeste/Nordeste	1	172.54 m	171.59 m	192.48 m	230.42m			
11	1.242 km	52° 07' 22.574"	Sudoeste/Nordeste	1	171.17 m	183.55 m	212.24 m	233.56 m			
12	1.896 km	50° 34' 04.830"	Sudoeste/nordeste	1	168.96 m	165.63 m	172.21 m	185.31 m	166.85 m		
13	706.06 m	57° 24' 27.503"	Sudoeste/nordeste	1	159.31 m	189.61 m					
14	3.195 km	84° 41' 39.118"	Leste /Oeste	10.053.471	135.49 m	156.09 m	176.36 m	210.25 m	169.75 m	228.26 m	180.39 m
15	851.07 m	142° 56' 28.147"	noroeste/sudeste	1	156.96 m	138.22 m	134.33 m				
16	2.252 km	145° 38' 09.722"	Noroeste/Sudeste	1	229.51 m	220.83 m	207.47 m	208.41 m	140.35 m		
17	2.211 km	143° 33' 36.251"	Noroeste/sudeste	1	240.45 m	191.97 m	163.71 m	152.66 m	165.02 m	149.20 m	
18	2.296 km	141° 39' 15.555"	Noroeste/sudeste	1	229.28 m	162.03 m	161.89 m	223.54 m	195.92 m	165.94 m	
19	2.598 km	142° 52' 05.436"	Noroeste/Sudeste	1	199.49 m	188.59 m	206.41 m	184.07 m	171.25 m	163.00 m	
20	2.544 km	141° 29' 39.018"	Noroeste/sudeste	1	182.76m	203.55 m	203.01 m	185.87 m	166.66 m	155.17 m	156.75 m
21	2.544 km	140° 11' 33.329"	Noroeste/sudeste	1	154.46 m	203.64 m	231.16 m	215.44 m	228.78 m	189.71 m	225.16 m
22	1.912 km	138° 46' 15.196"	Noroeste/Sudeste	1	191.47 m	194.08 m	184.93 m	151.91 m			
23	1.421 km	163° 13' 59.662"	Norte/Sul	1	210.04 m	208.91 m	210.22 m	210.22 m			
24	1.809 km	169° 13' 11.203"	Norte/Sul	1	170.96 m	210.90 m	194.13 m	192.34 m	214.81 m		
25	1.745 km	172° 04' 10.371"	Norte/Sul	1	172.92 m	192.98 m	159.11 m	179.44 m	161.77 m		
26	2.311 km	175° 25' 03.685"	Norte/Sul	10.063.752	163.88 m	164.36 m	165.00 m	181.04 m	168.38 m	196.43 m	
27	975.19 m	174° 34' 42.994"	Norte/Sul	1	138.88 m	151.35 m	174.49 m	188.82 m			
28	1.885 km	46° 54' 14.264"	sudoeste/nordeste	10.153.214	217.00 m	194.45 m	225.61 m				
29	1.198 km	55° 28' 11.984"	sudoeste/nordeste	1	178.73 m	205.79 m	180.77 m	199.68 m	223.99 m		

It is clear that the relief marks here called cuts are rectilinear enough for the software not to detect sinuosity in most of the traces, also draws attention to the number of cuts with exactly the same direction, most of them being Southwest/Northeast. Very intriguing facts for geological or geomorphological structures that exist in the Amazon environment, where the rainfall force over the years wears down the relief, sculpts channels and transports sediment in always very large proportions, both due to the vastness of the Amazon territory and due to the amount of rainfall and consequently drainage.

It is also observed that due to the subsurface flow of water, some concave shapes can be infiltration and/or drainage points. Even so, they are very peculiar forms and the data listed here are results of remote analysis and preliminarily made, and the possibility of complementing part of the information, or confronting the data collected by LiDAR technology with the reality of the field survey, should be considered.

FINAL CONSIDERATIONS

It is known that there are numerous reliefs with peculiar formations, whether in the form of dome, landing, table, among others, and that they are being reviewed and reinterpreted especially with the use of new technologies. The dense Amazon forest is still one of those places, whose knowledge in the scale of detail is still restricted, and that it must also be taken into account that it is a humid tropical environment with intense weathering and pedogenization, making the relief even more complex. The presence of rectilinear cuts that differ from the erosive patterns in the studied area may indicate new readings about the residual relief located in the north of the municipality of Apiacás, in Mato Grosso. It is evident that the erosive patterns acting in the area, for millions of years, have built very different forms from those identified by the *LiDAR sensor.* The images generated by this sensor help us to improve the understanding of the erosive processes of the present, as well as to list hypotheses about the formation of peculiar "chess" shaped reliefs.

In these places, so far inhospitable for detailed scientific research, it is very likely that with the development of new studies, we will also be able to identify new plant and animal species, as well as unprecedented archaeological structures. Considering that the area is little studied and the results demonstrated by the use of *LiDAR* technology indicate paths to the continuity of the research. In any case, it is worth noting that definitive proof will only be possible from a field research campaign that identifies material traces *in loco*, such as faults and fractures, types of soils and springs.

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