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Use of geotechnology in the study of the "Fallen Lands" in the Indigenous Land Barreira da Missão, Tefé/Amazonas/Brazil

Utilização de geotecnologia no estudo das "Terras Caídas" na Terra Indígena Barreira da Missão, Tefé/Amazonas/Brasil

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Abstract: The "Fallen Lands" are morphodynamic processes that occur mainly in Amazonian rivers and that cause significant changes in landscapes, including triggering material and human losses. This study aims to characterize and analyze physical-natural events by determining formation/change rates of Fallen Land processes in the Indigenous Land Barreira da Missão (Tefé/Amazonas) based on the use of geotechnologies. Methodologically, the tools available in Google Earth Pro were used to collect, process and interpret spatial data (elevation profile, drainage, vegetation and soil coverage) and human activities (economic and housing occupation) along the erosion scars. As an analytical parameter, 20 features were determined (five in each indigenous community) demonstrating the variety of the process in its geometries, dimensions and spatio-temporal behavior, such as Feature 05 located in Barreira de Baixo, with an 80 meter perimeter of the erosion scar. The results identified can be useful for the implementation of social and environmental public policies aimed at improving the quality of life of the populations that inhabit these areas, considering that the process intensifies over the years.

Keywords: Surface processes; Satellite images; Brazilian Amazon.

Resumo: As "Terras Caídas" são processos morfodinâmicos que acontecem principalmente em rios amazônicos e que causam significativas alterações nas paisagens, desencadeando inclusive perdas materiais e humanas. Este estudo tem como objetivo caracterizar e analisar os eventos físico-naturais a partir da determinação de taxas de formação/alteração dos processos de Terras Caídas na Terra Indígena Barreira da Missão (Tefé/Amazonas) com base no emprego de geotecnologias. Metodologicamente foram utilizadas as ferramentas disponibilizadas no Google Earth Pro para coleta, processamento e interpretação de dados espaciais (perfil altimétrico, drenagem, cobertura vegetação e solo) e atividades humanas (econômicas e ocupação habitacional) ao longo das cicatrizes erosivas. Como parâmetro analítico foram determinadas 20 feições (cinco em cada comunidade indígena) demonstrando a variedade do processo em suas geometrias, dimensões e comportamento espaço-temporais, a exemplo da Feição 05 localizadas na Barreira de Baixo, com 80 metros de perímetro da cicatriz erosiva. Os resultados identificados podem ser úteis para a implementação de políticas públicas sociais e ambientais visando melhorar a qualidade de vida das populações que habitam essas áreas, tendo em vista que o processo se intensifica ao longo dos anos.

Palavras-chave: Processos superficiais; Imagens de satélite; Amazonia Brasileira.

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1. Introduction

The uses of techniques employed in landscape studies are capable of supporting the extraction, manipulation, treatment and interpretation of data and spatial information (Geoinformation), and supported by Geographic Information Systems, Remote Sensing, Geostatistics, Cartography, Geodesy and others, such as Florenzano (2011) and Xavier-da-Silva and Zaidan (2011) state that these techniques are fundamental in the investigation of processes that are located in a spatial and temporal, helping to understand the patterns of use, occupation and land cover, impacts, in addition to physical-natural characteristics that form the landscape (MEINIG; 2002; CONTI, 2014; BALDIN, 2021).

According to Freitas and Albuquerque (2012), the term "Fallen Lands" is used to identify an erosive modality due to natural causes due to the process of sedimentation, deposition and erosion that occur depending on the configuration of the Amazon river plain, results of a combination of different factors (where the climate issue stands out) considering the high rainfall levels in the region, also associated with the fragility of the material on the banks, which suffer periodic pressure due to the dynamics exerted by the river water. Added to this is the paleoclimatic influence of the quaternary and the structural and (neo)tectonic aspects for the formation of the current Amazon river system, guaranteeing morphogenetic and morphodynamic interactions (ROSSETTI; COHEN; PESSENDA, 2017; SOARES, et al. 2021) for the formation of today's landscapes.

"Fallen Lands" are frequent morphodynamic processes on the banks of Amazonian rivers, especially along the floodplains of the River Solimões, associated with the seasonality of the flood, judging by the need for studies on spatial and temporal dimensions in areas of dry land.

The aim of the study is to characterize the areas based on physical-natural elements (slope, drainage, vegetation and soil) and human occupation (economic activities and housing occupation); Determination of the rates (quantitative aspects) of formation and alteration of the identified erosion processes and their proximity and link (qualitative aspects) with the Indigenous Land (T.I.) in question, despite the proximity to residences; and use geotechnology tools as a subsidy for environmental analysis in the time frame between 2013 and 2022. In view of the above, the following study aims to characterize and analyze the physical-natural events based on the determination of formation/alteration rates of the "Fallen Lands" processes in the Indigenous Land Barreira da Missão (Tefé/Amazonas) based on the use of geotechnology.

It is important to highlight that this study area is subdivided into four neighboring villages (Barreira de Cima, Betel, Barreira do Meio and Barreira de Baixo) located on the right bank of the River Solimões, in the municipality of Tefé/Amazonas. The choice of the study area was initially made for the following reasons: a) the area presents evident and accentuated morphologies of "Fallen Lands" events; b) a study in the rural portion of the municipality, also covering an Indigenous Land; c) possibility of interrelationship between physical-natural and socioeconomic elements; and, d) capacity to assist in local scientific production.

The study is justified by the identification of the "Fallen Lands" processes in an area of dry land, so that for geographic science it is of great relevance as it allows a scientific reading of natural phenomena. Furthermore, the recording and identification of these processes can serve as political support for the implementation of public social and environmental policies aimed at the quality of life of the populations that make use of these spaces.

2. Theoretical bases

Erosive processes are natural and of fundamental importance in modeling the relief and in the constant renewal of soils (DRUMOND, 2015), on the other hand, an imbalance in the geomorphological system may occur, of natural origin or by anthropic action that culminates in the acceleration of these processes. Erosive processes, often causing irreversible damage to the landscape and, sometimes, to the economy of areas affected by these processes. Erosion is a natural phenomenon, operating on the surface of the earth since its formation and subject to interference by anthropogenic activities, which can lead to an intensification of incidence rates (SELBY, 1993; DRUMOND, 2015; SUERTEGARAY; SILVA, 2020).

Within this scope, according to Albuquerque (2010) the "Fallen Lands" are soil displacements and there are countless and diverse landslides, landslides, landslides and collapses that occur in the Amazon region, with different dimensions and magnitudes, being noticeable in deposits of recent sediments and in older consolidated rocks, also studied recently by Ferreira, Lima and Rabelo (2022) and Nunes (2022).

Rivers in the Amazon region develop their channels in deposits of the modern plains formed by themselves or older deposits that form the substrate of the river basin, and in some they outcrop forming the banks of the channels. The predominantly hot humid and hot super humid climate factor in South America and its geographical position with irregular rainfall events, combined with the hydrological cycle and the progressive elimination of the equatorial forest, will intensify the cyclical processes of the "Fallen Lands" in the region (SILVA; NODA, 2016; MATOS, 2020; OLIVEIRA, 2022).

The aforementioned "Fallen Lands" comprise, according to Albuquerque (2010), different types of landslides based on: the type of material subject to movement; of the topography with its specific forms and characteristics over which the movement occurs; of the area's vegetation cover due to movement; the weather; water and how long the phenomenon lasts. In the Amazon region, the majority of landslides will occur on river banks, considering that the banks have very steep slopes and may be devoid of or covered by vegetation. Another factor cited is the energy of erosive currents against the banks, combined with precedents that will generate such a process.

The causes of the "Fallen Lands" (figure 01) are related to factors such as: erosive action of surface waters and the water table, the energy of river currents and the neotectonic influence that plays an important factor in the configuration of the Amazonian landscape (ALBUQUERQUE, 2010), so that neotectonics has been blamed for larger events, especially along rivers, most in areas of megafractures or large faults. The classification follows two patterns: Rotational Movement that gives rise to a lowering of blocks that detach along the vertical plane, without making changes to the internal structures; and the Translational Movement that causes landslides of rocks or soil along inclined planes with breakage of material that is deposited at the foot of the inclined plane.

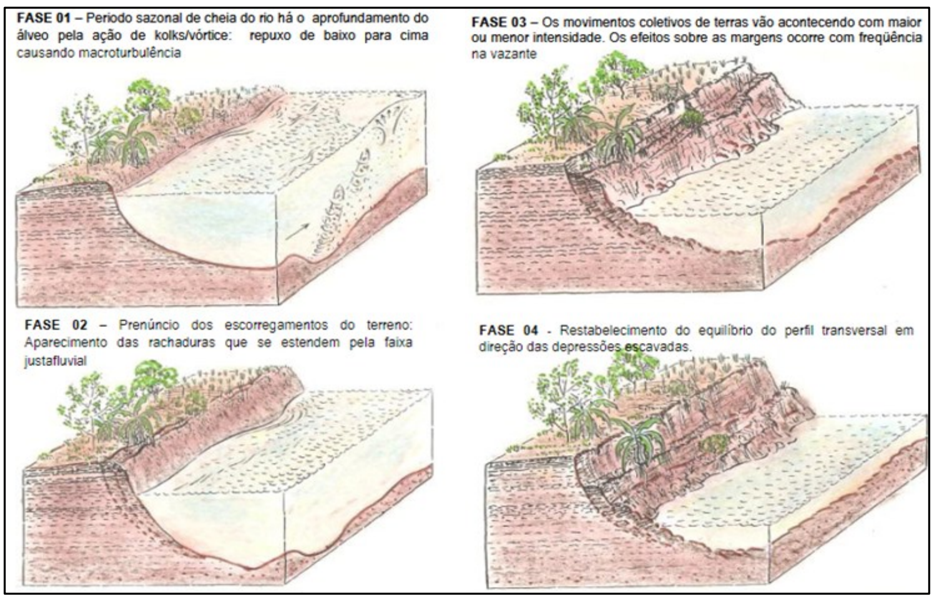

Figure 01 – Mosaic with stages of river erosion/"Terras Caídas".
Source: Pacheco; Brandão e Carvalho (2012).

In this process of identifying and monitoring the "Fallen Lands", geotechnologies are used, especially in monitoring the space-time dynamics (as observed sequentially in Phases 01, 02, 03 and 04 of the previous figure) as well as the consequences, which, according to Santos, et al (2012), over the years the environmental concern aimed at conserving natural resources has been a global concern, and, in this sense, geotechnologies have been of fundamental importance for temporal monitoring environment events. Thus "applied research [...] will depend on Geotechnologies, as it is known that location is a vital component for decision making and that, in the future, with technological advancement, new ways of obtaining and processing data will be implemented. space data" (SANTOS et al, 2012, p. 22).

Increasingly, research aimed at environmental issues will use geotechnologies as a fundamental instrument. Data collection, monitoring, treatment and interpretation, determining the knowledge of the location or geographic distribution of objects and phenomena has always been important, understood as geographic reasoning, that of locating and giving meaning to the places where objects or phenomena occur (NASCIMENTO et al, 2015).

In this context, Geographic Information Systems (GIS) stand out for allowing the storage, organization, manipulation, treatment and output of georeferenced data in computerized environments, simultaneously comprising several systems, such as programs, equipment, procedures, data and human resources, the which can be observed in Silva's contributions; Ladwig and Back (2024), Sato et al. (2024) and Silva; Rabelo and Nunes (2024).

With tools that allow the exploration of the entire terrestrial and/or oceanic surface, both in plan view and observation with the variation in relief altitudes, measurements of area, distance and elevation, creation of topographic profiles, markings, path layouts, delimitation of areas, activation of layers and external sources and visualization of historical images of the same location; allowing the user not only to simulate a flight over any location on the planet, but it can also be used in the analysis of environmental and/or urban phenomena (NASCIMENTO, 2015).

Geotechnologies encompass the use of geospatial technologies for the acquisition, analysis and representation of information, "porém, o que tem revolucionado os processos tradicionais de utilização da informação é a maneira como ela pode ser rapidamente processada e utilizada para diferentes objetivos pelo modo de sua apresentação, ou seja, georreferenciada ou mapeada" (ROSA, 2005, p. 82). Furthermore, Florenzano (2011, p. 31) highlights "que as imagens de satélite, por fornecerem uma visão ampla e multitemporal da superfície terrestre, evidenciam os ambientes e suas transformações". When applied to indigenous lands, these tools play a crucial role in the management, protection and preservation of these areas, in addition to being used to map and delimit the limits of indigenous lands, helping to establish property and use rights, as well as helping to sustainable management of natural resources.

3. Methodological bases

3.1 Study area

The study area is located in the State of Amazonas, in the municipality of Tefé (with a total population of 73,669 people according to the 2022 Demographic Census and approximately 672km from Manaus, the state capital) in the Indigenous Land Barreira da Missão, with a distance of approximately 10km from the municipal seat (figure 02). According to data from the Instituto Sócio Ambiental (ISA, 2024), Indigenous Land was officially approved on October 29, 1991, being a milestone in the fight for the demarcation of Indigenous Land in Brazil, representing the right of indigenous peoples to preserve their traditions, live in the Indigenous Land (T.I.) 788 people of the Kambeba, Ticuna, Miranha, Kaixana and Wioto ethnic groups, in an area of 1,772 acres. It is located on the right bank of the River Solimões, towards the headquarters of the municipality-TI Barreira da Missão, via the waterway.

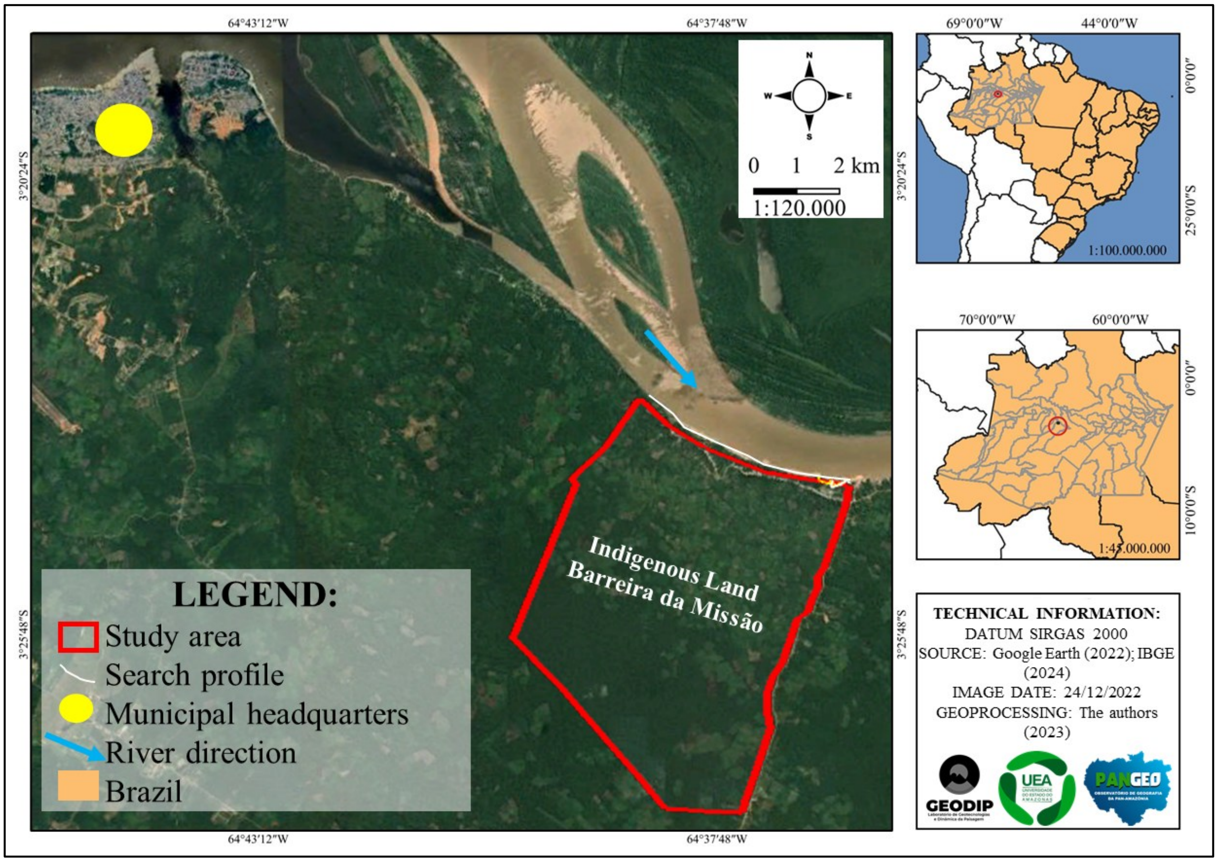

Figure 02 – Identification of the T.I. and the study area.
Source: Authors (2023) based on Google Earth (2022).

3.2 Methodological procedures

This research followed a sequence, sometimes concomitant and sometimes subsequent, of numerous methodological steps (figure 03), considering the specificities of the study and that, as it is T.I., those responsible for this study prepared a Term of Consent, later approved and signed by the indigenous leaders of each of the T.I. communities. Shortly after the collection, two field expeditions were carried out (08/26/2023 and 10/07/2023) leaving the municipality headquarters (Urban Zone) by river in common transport (canoe and tail motor), with a time of journey of approximately one hour, to collect geographic coordinates, photographic records, determine points and analyze existing processes.

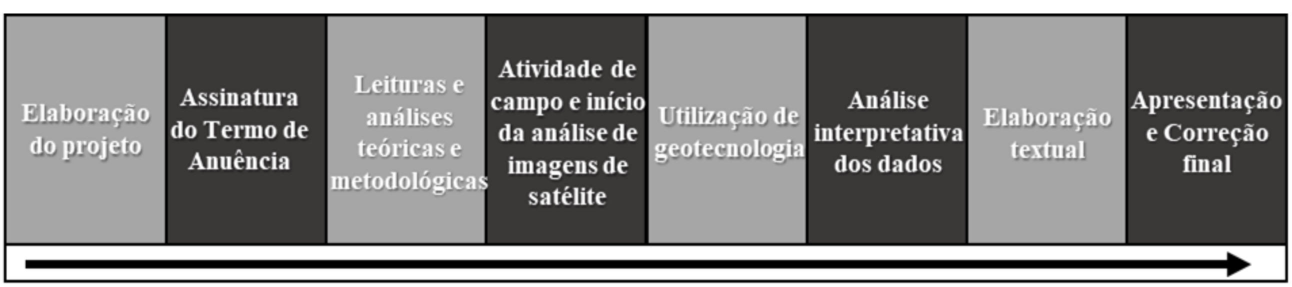

Figure 03 – Methodological Organizational Chart.
Source: Authors (2023).

In this way, through the analysis of satellite images from Google Earth from the years 2013 and 2022, considering that the image available in the "historical images" tool menu with better resolution is dated August 2013 and the most recent in October 2022. The images from satellite are linked to LandSat/Copernicus and CNES/Airbus. Methodologically it was based on Prina et al (2011), Pereira, Guimarães and Oliveira (2018), Barbosa, Listo and Bispo (2022) and Velastegui-Montoya et al (2023) to define and analyze the following elements:

- Erosion: The line option was activated and the entire route of the area was covered on the two dates 2013-2022, and 20 features were measured along the researched area to then compare the historical images identifying the distances of the erosion process in the T.I.. Measurements of scars using the "Show historical images" functions to view images, year by year, invalidating only those that did not have good spatial resolution quality (for example, September 2020 due to the amount of clouds) and "Add path" for the contour of the erosive scars and subsequent measurement of the perimeter.
- Topographic Profile: On the left side, activate the "terrain" layer and then display the terrain in relief on the screen. Following the "tools" menu, choose "ruler" to draw the line in the desired area and identify the slope levels on the screen;
- Drainage: Analyzing the image from the Google Earth system within the time frame of the research (2013-2022), for example, the distance from the water depth in the specific area where the measurements described were made in different features of the area for this purpose. of comparison in the two periods analyzed.
- Vegetation, Soil, Economic Activities and Housing Occupancy: based on an interpretation key based on elements such as tone, color, texture, shape, size and pattern of Google Earth Pro images and photographic records.

4. Results and discussion

The adoption of geotechnological resources was based on the tools made possible by Google Earth, which, according to Nascimento (2015), stands out for being free and easy to manipulate, allowing people of different ages to use it, with the aim of representing the surface. Of planet Earth as long as you have access to the internet and can obtain satellite images compiled by a wide range of commercial and public sources. With the on-site visit, the existence of numerous erosive scars resulting from the "Fallen Lands" phenomenon was identified in the study area, and which, based on the analysis of satellite images (between 2013 and 2022) made available on Google Earth, as shown in Table 01.

Table 01 – Dimensions (in meters) of erosive scars resulting from the Fallen Lands (2013/2022).

Erosive scars	Indigenous communities within T.I. Barreira da Missão			
	Barreira de Cima	Betel	Barreira do Meio	Barreira de Baixo
Scar 01	9m	12m	32m	21m
Scar 02	8m	20m	20m	76m
Scar 03	13m	24m	15m	78m
Scar 04	16m	36m	12m	73m
Scar 05	12m	31m	19m	80m
LEGENDA:				
[red] Larger dimension erosive scars for the community		[green] Smallest dimension erosive scars for the community		

Source: survey data (2023).

The 20 features identified (five in each community) demonstrate the variety of the process even over approximately 3.4km, considering both the geometry (shape) and the dimension itself. From upstream to downstream, it is important to note that there is a progressive increase in the rates of erosion, in Barreira de Cima, for example, the sum is 58m (the largest scar has a perimeter of 16m while the smallest has 8m). In Betel the sum is 123m (the largest scar has a perimeter of 36m and the smallest has 12m), while in Barreira do Meio the sum is 98m (the largest scar has a perimeter of 32m while the smallest has 12m) and, finally, in Barreira de Baixo the sum is 328m (with scars varying between 21m and 80m). Based on these data, the spatial and temporal dimension of the object of study is analyzed, so that there is the possibility of comparisons between the communities themselves, interpreting, here, the greater complexity identified in Barreira de Baixo.

It should also be noted that the largest erosion process is on the edge of the T.I., at the end of Road the EMADE (figure 04) already studied by Silva Neto and Aleixo (2014), Conceição, Silva Neto and Aleixo (2017), Mesquita (2017) and Nunes (2022), who identified the fragility of the soil and sediments in the region, in addition to the opening of roads dating back to the mid-1960s and 1980, where land occupation has been accelerating since then. In the specific case of the Emade road, it was opened based on state and federal interest with the aim of promoting the palm oil project as a source of energy, even though the processes that transform and alter the landscapes in the region demonstrate the insufficiency of territorial planning and management policies, which are seen in the increase in deforested areas, the increase and intensification of erosion processes (SILVA NETO; ALEIXO, 2014; MESQUITA, 2017).

Figure 04 – Highlight the existing process at the end of the EMADE road and its connection with the processes within T.I., especially in the Barreira de Baixo area.
Source: Authors (2023) based on Google Earth (2022).

The distribution of vegetation is an important factor for soil support. In the images analyzed (2013-2022) it was observed that in areas where the vegetation layer is denser, erosion processes are smaller and where removal occurred (exposed soil, due to natural or anthropogenic action) the processes are greater, since the soil is exposed on the bank, associated with the periodic seasonality of the region's rivers, making it susceptible to significant soil losses and compromising the stability of the banks (ALBUQUERQUE, 2010).

In the study area there is no economic enterprise, since the indigenous populations livelihood is mainly focused on agriculture, hunting and fishing, although the population has already suffered from the influence of the urban area, mainly in their eating habits, and for the implementation of Federal Government social programs that contribute to the economic stability of populations (ISA, 2024). In the specific case of cassava plantations targeted at flour production, these are concentrated in areas far from the riverbank. Another activity is the small-scale agriculture of small animals (chickens, pigs and others).

Also linked to local human actions, as can be seen in the satellite images (Figure 05) and verified during the on-site visit, the buildings and residences are close to the bank of the "barranco", an area characterized by risk factors, such as the phenomenon of the "Fallen Lands". However, despite the obvious environmental risks, the land is a conquest for the indigenous populations, who already have a bilingual public school and an indigenous health center.

It is observed, still according to Table 01, in the first feature that the erosion process is greater in the middle of Barreira do Meio followed by Barreira de Cima. In feature 02 the erosion process is most evident in Barreira de Baixo followed by Barreira do Meio and Betel with the same dimensions. In features 3, 4 and 5, an increase in these processes in Barreira do Meio and Baixo stands out, as identified and illustrated in figure 06.

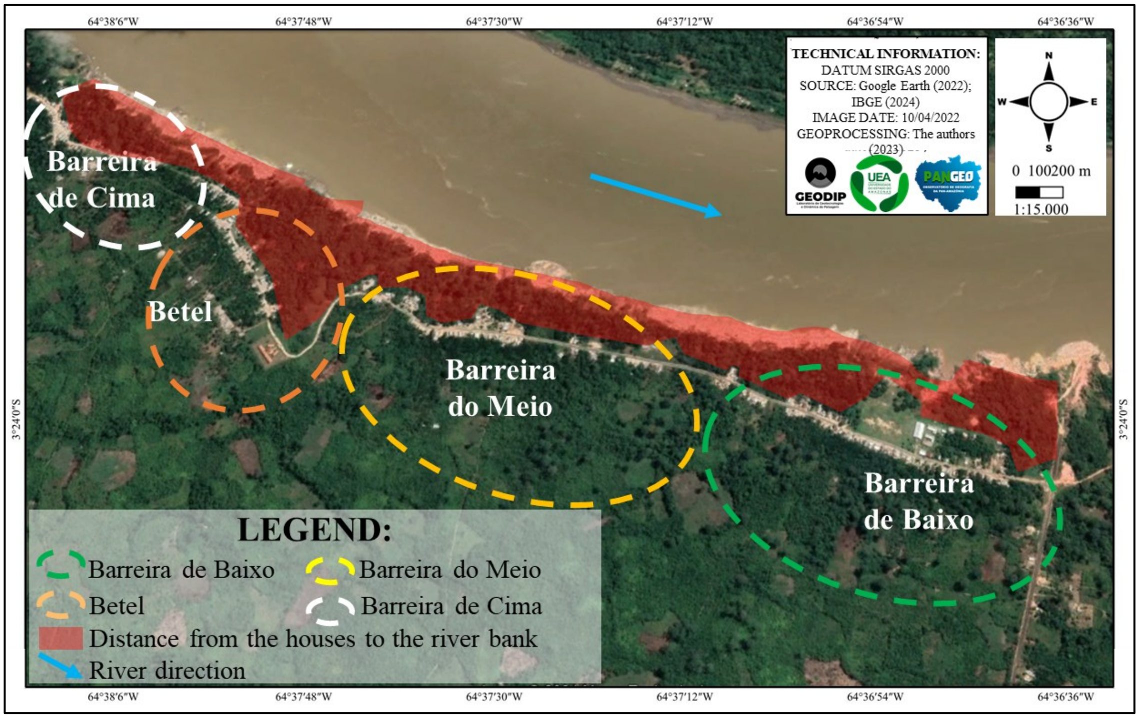

Figure 05 – Distance between residences and the bank of the River Solimões. Organization: the authors (2023) based on Google Earth (2023).

Figure 06 – Erosive Process.
Source: Authors (2023) based on Google Earth (2023).

This finding of greater events of fallen land in the final T.I. measurements is observed in situ, at the beginning of the area, and, on the field route by river, greater vegetation cover is observed, which decreases during the route, becoming increasingly visible erosion processes. Regarding this, Drumond (2015) reveals that the erosion process is a natural and necessary event for soil shaping, however it can intensify with human action and the removal of vegetation cover. In this sense, it is possible to identify the phenomenon of "Fallen Lands", in areas where existing vegetation cover was removed or destroyed, leaving the soil exposed to erosion. In recent images, the growth of vegetation cover in landslide areas with trees is observed. and root plants that help stabilize the soil. As the vegetation cover is established, other (secondary) plant species begin to appear in the area, creating a sequence of changes in vegetation called ecological succession, but not providing sustainability to the land.

In Figure 07 are the records made in the field work and illustrate the erosion processes in the period of August 2023, and once again confirming the data analyzed in the images produced by Google Earth, with regard to the characteristics of the area, mainly focused on vegetation, soil, human occupation and erosion processes. Demonstrating how intense these phenomena have been (figure 08) in certain areas of the T.I., considering that the banks are an area of dry land, Ferreira, Lima and Rabello (2022) explain that numerous processes occur in the Amazon rivers that are related to river erosion, among which the movements of the "Fallen Lands" stand out as being a common process in white water rivers such as the River Solimões.

Figure 07 – Image mosaic of the study area.
Source: Direct Search (2023).

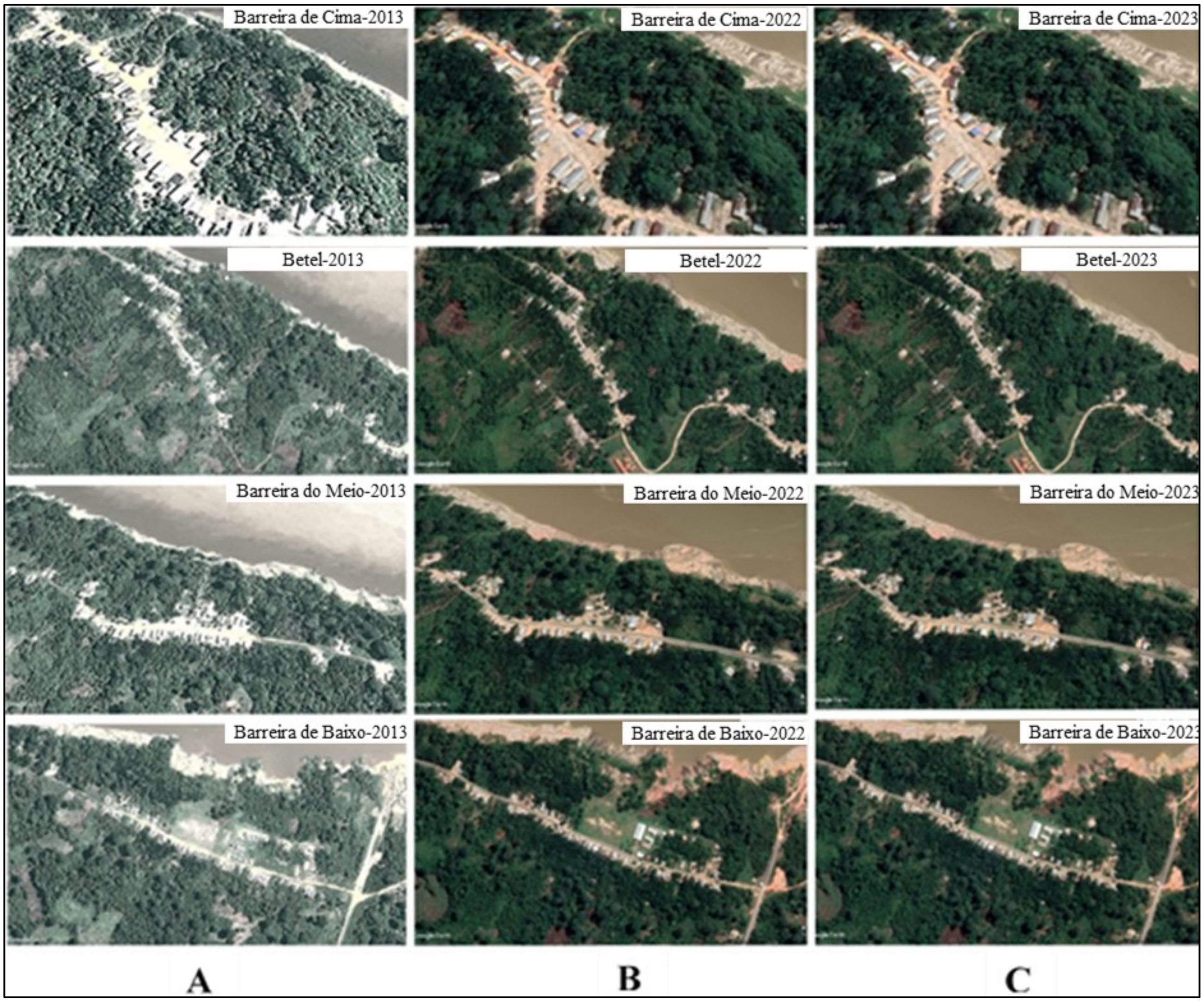

Figure 08 – Mosaic of images (2013/2022/2023) of each community.
Source: Authors (2023) based on Google Earth (2023).

To analyze the slope, historical images from 2013 and 2022 were also evaluated, identifying the lowest and highest slope. For the period 08/2013, it was identified that the slope varies from 28m in the middle of Barreira de Cima and 58m in the middle of Barreira de Baixo. For 10/2022 there was a variation in slope of 31m in Barreira de Cima and 60m in Barreira de Baixo. Using Google Earth as a specific example, four features were taken in water depth measurements, one in each community, and from the images it was possible to determine that there was a significant increase in water depth during the research period, justified by the direct interference of seasonality of rivers (ebb and flood).

In August 2013, for example, the distance from the water depth to the bank was 23m (Barreira de Cima), 32m (Betel), 37m (Barreira do Meio) and 59m (Barreira de Baixo), while in October 2022 the values were 65m, 65m, 89m and 92m, respectively, forming sandy terrain resulting from the drop in the river level, appearance of sandy river beaches and the collapse of ravines. For the measurements analyzed, it is important to consider (PÁRRAGA, 2013; MARENGO; FISCH, 2021) the periods of the year, in August in the Amazon is the beginning of the ebb of the rivers and the month of October is when the ebb is most intense, so there is a significant difference in values, as can also be seen in figure 09.

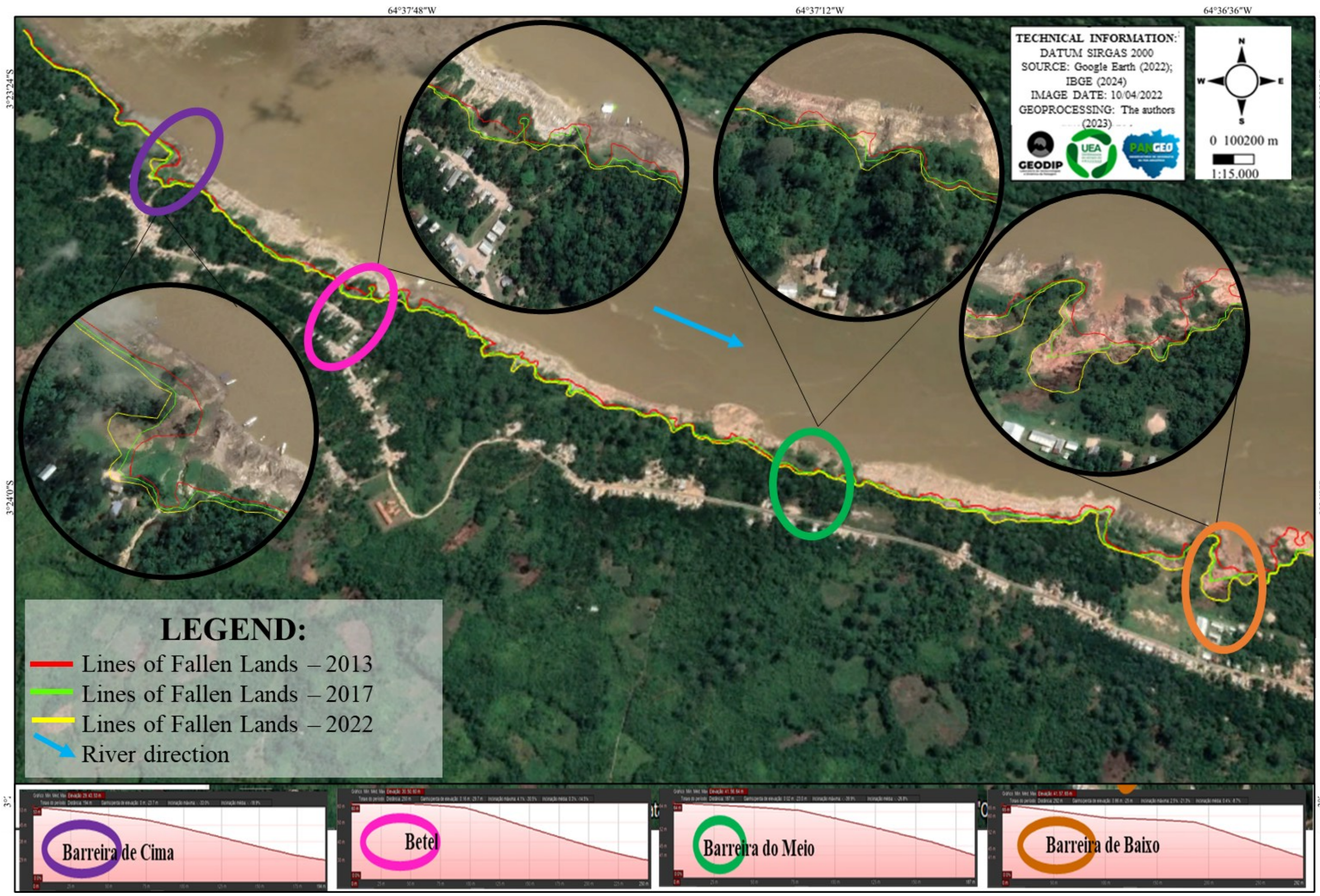

Figure 09 – Representative board, highlighting a zoom to some evolutionary scars (2013/2022) of "Fallen Lands" and elevation profiles by indigenous community.
Source: Authors (2023) based on Google Earth (2023).

The image mosaic shows records from Google Earth respectively of the areas of Barreira de Cima, Betel, Barreira do Meio and Barreira de Baixo. Images of the same area in different years and periods: the first image in column "A" corresponds to 08/2013, the second from 10/2022 in column "B" and the third 08/2023 in column "C", it is important to highlight that the images are not georeferenced, as they are saved in JPG format in the system itself. In these images it is possible to observe changes in vegetation cover, soil, and housing occupation in different periods, in addition to scars from the Fallen Lands, in numerous episodes of mass movements, such as the most recent one that took place at 11:30 am (approximate time) on the day September 26, 2023, in Barreira de Cima (figure 10), with gradual washout processes during the rest of the day.

Figure 10 – Landfall event in Barreira de Cima.
Source: Direct Search (2023).

Vegetation gradually decreases, influenced by housing occupation in the T.I.. The soil in certain areas, such as in the vicinity of Barreira de Baixo, has been suffering landslides, which, associated with the region's natural factors, may have caused a higher rate of fallen land, as was seen both in the images and in the field research. Infiltration and surface flow waters and river currents are also important factors. Infiltration water penetrates the pores between the unconsolidated sediment particles, increasing the mass and consequently contributing to local imbalance (ALBUQUERQUE, 2010). The changes may vary depending on local conditions, rainfall patterns and temperatures, which in the Amazon can worsen erosion and soil degradation, making river banks more susceptible to erosion processes.

5. Final considerations

Based on the results obtained through geotechnological analyses, erosion scars, slope, vegetation cover, which according to visual analysis of the images has been gradually decreasing, and housing occupation in the study area were identified. In this sense, it appears that the use of Google Earth contributes as a promising tool in geographic surveys of the study area, through which it is possible to describe the evolution in areas of susceptibility to fallen lands, which associated with sandy and clayey soils, they develop in areas of recent deposition of sediment transported by rivers and streams. However, the work developed analyzed the temporality of the years 2013 to 2022 of the Indigenous Land Barreira da Missão, where the phenomenon of "Fallen Lands" stands out, for which the Google Earth system was fundamental in the development of research to identify and produce material for analysis.

When analyzing the results, it is noted that the erosive process of the "Fallen Lands" appears in the results, because as discussed, the phenomenon is visible, as well as the consequences that were caused and this reflects on the way of life of the populations, who live in T.I., and who need to migrate with their homes, moving them further and further away from the banks, specific areas that are increasingly hilly, making access to the river difficult, which is a widely used transport route to the municipality's headquarters. During the research it was possible to observe that the area has suffered major soil losses due to the Fallen Lands on the banks of the river, influenced by several natural and anthropogenic factors, making the area more prone to erosion processes.

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