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Hydrogeomorphometry of the Paraíso river basin: information to help manage natural resources in Western Amazonia

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Abstract: The analysis of the characteristics of the landscape is the first step in the planning and proper management of natural resources. In view of the above, this study aims to provide information on landscape characteristics in the Paraíso river microbasin, Western Amazon, Brazil. The information is associated with geometric, topographic and hydrographic parameters, and ground cover dynamics, which was obtained using the QGIS, Google Earth and TrackMaker Free software, altimetric images (ALOS satellite), ground cover (Landsat 5 and Landsat 8 satellites), and data from the literature. The Paraíso river microbasin has an area of 50.76 km^2 , elongated shape, low susceptibility to flooding, altitudes between 234 m and 458 m, predominance of wavy relief, medium sized river, 5th order dendritic drainage pattern, high spring density, very high drainage density, meandering main channel, low maintenance coefficient and high concentration time. From 1984 to 2020, the agriculture area exceeds over the areas of native forest, reaching 80.32% of the microbasin area and 64.21% of the riparian area in the last year. The microbasin has a high potential for the development of agricultural systems, however it is recommended to adopt conservationists' soil and water management practices, the maintenance and / or recovery of native forests protected by law, and the integration of the tree component in economic systems (ex: agroforestry and agrosilvipastoral systems). These recommendations aim to reconcile economic development and the conservation of natural resources, both of which are essential for the sustainable development of the region.

Key words: remote sensing; natural resources; environmental planning; sustainable development

1 Introduction

The Paraíso River watershed is environmentally, socially, and economically important, as it is part of the Guaporé River basin, and a sub-basin of the Vermelho River (SEDAM, 2002), which covers 52 private agricultural establishments (INCRA, 2019). The ecotone formed by the upstream part of the Guaporé and Paraguay rivers forms an ecological corridor that connects the biogeographic regions of the Amazon and the Pantanal, which are recognized for their high importance of biodiversity (Silva, et al., 2015). Private agricultural establishments play an important role in the economy of Brazil's northern region, but there are limitations to the development of these establishments, due to various factors including environmental issues, technological backwardness and a lack of technical assistance (Castro, 2013). In this context, there is a need to adequately plan the management of natural resources in order to reconcile sustainable development in the region.

The efficiency of natural resource management depends on the quality of the information included in planning, which is related to environmental characteristics, including land use and occupation. This information makes it possible to quantify the natural resources available in the region, delimit priority areas for the conservation of these resources, analyze agricultural potential, and select the most efficient soil and water management practices to mitigate the impacts of anthropic activities on the environment (Silva, et al., 2021).

Quality information can be obtained at a low financial cost and in a relatively short time using geotechnologies, even in large areas (Soares, et al., 2019). Due to these advantages, this methodology has become increasingly used in recent years, which can be seen in the work carried out in the Jacuri (Panza, et al., 2020), Alto Rio Escondido (Vendruscolo, et al., 2020a), Médio Rio Escondido (Vendruscolo, et al., 2020b), Gavião (Donegá, et al., 2021), Três Galhos (Silva, et al., 2021) and Mutum (Souza, et al., 2021).

In view of the above stuation, this work aims to provide information on the characteristics of the landscape and analyze the dynamics of land occupation in the Paraíso river basin, Western Amazonia, Brazil.

2 Methodology

The Paraíso river basin is part of the Vermelho river sub-basin, located in the municipality of Colorado D'Oeste (Figure 1). This region has a Monsoon-type climate, with average temperatures between 24°C and 26°C (Alvares, et al., 2013), and average annual rainfall of 1,728.9 mm to 1,843.7 mm, which occurs mainly in the months of November to March (Franca, 2015).

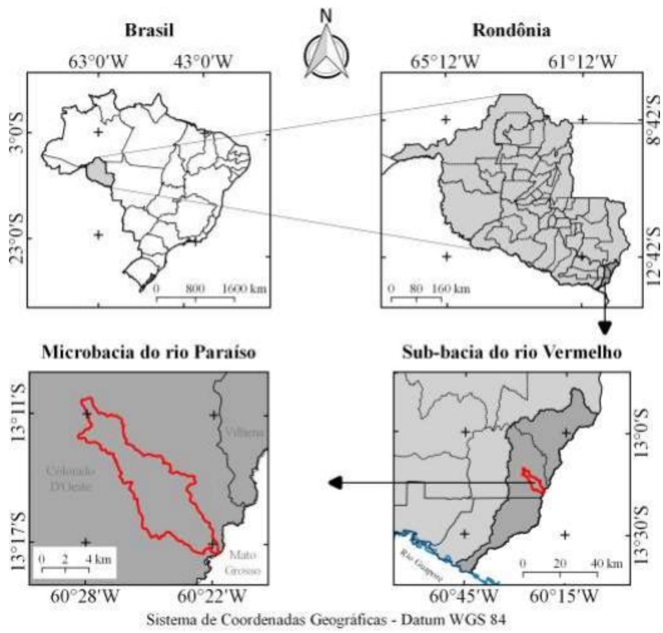

Figure 1. Location of the Paraíso river basin, Western Amazonia, Brazil

Source: Authors

2.1 Landscape features

Landscape characteristics are associated with geometric parameters (area, perimeter, shape factor, circularity index and compactness coefficient), topography (altitude and slope), hydrography (drainage network pattern, river order, density of springs, drainage density, maintenance coefficient, sinuosity index and time of concentration), land use and land cover. QGIS 2.10.1 (Pisa), Google Earth and TrackMaker Free (Version 13.9.596) software, images from the ALOS (ASF, 2017), Landsat 5 and Landsat 8 satellites, and equations available in the literature were used to acquire the information and draw up the maps. Therefore, the quantitative methodology was initially used to acquire numerical data, followed by the qualitative methodology to interpret the numerical data and develop ideas about each parameter, corroborating Pereira et al.

(2018). This work was carried out in five stages:

Stage 1- Geometric characteristics

Area and perimeter: at first, the micro-watershed was delimited automatically using the TauDEM tool. (Steps: Pit Remove < D8 Flow Directions < D8 Contributing Area - 1st version < Stream Definition By Threshold < Editing the D8 Contributing Area - 2nd version) and altimetric images from the AlOS satellite, with a spatial resolution of 12.5m. The matrix file generated in TauDEM was then transformed into vector format ("polygonize" tool), dissolved ("dissolve" tool), smoothed ("simplify geometry" tool) and adjusted in Google Earth software, taking into account the characteristics of the drainage network and relief. The area and perimeter were then calculated using the "field calculator" tool.

The shape factor, circularity index and compactness coefficient parameters were calculated using equations 1 (Villela & Mattos, 1975), 2 (Christofoletti, 1980) and 3 (Villela & Mattos, 1975), and compared with data from the literature (Table 1)

$$F = \frac{A}{L^2} \quad \text{(Equation 1)}$$

Where: F = shape factor; A = area of the watershed (km²); L = length of the watershed axis (km)

$$Ic = \frac{12{,}57xA}{P^2} \quad \text{(Equation 2)}$$

Where: Ic = circularity index; A = area of the watershed (km²); P = perimeter of the watershed (km).

$$Kc = 0{,}28x\frac{P}{\sqrt{A}} \quad \text{(Equation 3)}$$

Where: Kc = compactness coefficient; A = area of the watershed (km²); P = perimeter of the watershed (km)

Table 1. Classification of geometric parameters: shape factor, circularity index and compactness coefficient

Parameter	Limit	Class
Form factor [1]	< 0,50	Not prone to flooding
	0,50 – 0,75	Medium tendency to flooding
	0,76 – 1,00	Subject to flooding
Circularity index [2]	< 0,51	Elongated shape
	0,51 – 0,75	Intermediate shape
	0,76 – 1,00	Circular shape
Coefficient of compactness [1]	1,00 – 1,25	High propensity to flooding
	1,26 – 1,50	Medium flood prone
	> 1,50	Not prone to flooding

Source: [1] Lima Júnior, et al. (2012); [2] Silva(2012)

Stage 2 - Topographical features

Altitude and slope: the minimum and maximum altitudes were obtained directly from the altimetric image, and the average altitude was measured using the "statistics by zone" tool. The slope was measured from the altimetric image using the "Digital Elevation Model" tool, then classified to obtain information on the relief, influence on the spread of fires and suitability for agricultural mechanization (Table 2).

Table 2. Classification of slope in relation to relief, influence on the spread of fires and suitability for mechanization for agricultural mechanization

Parameter	Class	Slope (%)
Relief[1]	Flat	0-3
	Gentle undulating	3-8
	Wavy	8-20
	Strongly undulating	20-45
	Mountainous	45-75
	Steep	> 75
Influence on the spread of fires[2]	Low	≤ 15
	Moderate	16-25
	High	26-35
	Very high	36-45
	Extremely high	> 45
Suitability for agricultural mechanization[3]	Extremely fit	0-5,0
	Very fit	5,1-10,0
	Apt	10,1-15,0
	Moderately fit	15,1-20,0
	Not fit	> 20,0

Source: [1]Santos, et al., (2013); [2]Ribeiro, et al. (2008); [3]Höfig & Araujo-Junior (2015)

Stage 3 - Hydrographic characteristics

Drainage network: the rivers (trails) were initially drawn up using the "add path" tool in the Google Earth software. The trails were saved in KML (Keyhole Markup Language) format and merged in TrackMaker Free software with the "Pencil" tool to form the drainage network, then the file was converted to Shapefile (SHP) format.

Drainage network pattern: this was identified through a visual comparison between the spatial distribution of the drainage network of the watershed under study and a catalog containing the main drainage patterns, provided by Parvis (1950).

River order: it was classified using the "Strahler" tool, where the springs originate the rivers of first order, the meeting of two 1st order rivers forms a 2nd order river, the meeting of two 2nd order rivers forms a 3rd order river, and so on (Strahler, 1954).

Density of springs: it indicates the region's water potential. The higher the value, the greater the potential (Cherem, et al., 2020). This parameter was measured using equation 4 (Christofoletti, 1980).

$$Dn = \frac{N}{A}$$

(Equation 4)

Where: Dn = density of springs (springs km^{-2}); N = number of springs; A = area of the watershed (km^2)

Drainage density: it represents the degree of development and efficiency of the micro-basin's drainage system (Villela & Mattos, 1975), and was calculated using equation 5 (Horton, 1932).

$$Dd = \frac{L}{A}$$

(Equation 5)

Where: Dd = drainage density (km km^{-2}); L = length of the drainage network (km); A = area of the watershed (km^2)

Maintenance coefficient: it corresponds to the area required for the watershed to maintain each meter of river perennial, and was calculated using equation 6 (Santos, et al., 2012)

$$Cm = \frac{1}{Dd} x1000$$

(Equation 6)

Where: Cm = maintenance coefficient (m^2 m^{-1}); Dd = drainage density (km km^{-2}).

Sinuosity index: this parameter is related to the speed of the water flow, with a reduction in speed being observed with increasing sinuosity, and was calculated using equation 7 (Villela & Mattos, 1975)

$$Is = \frac{L - Dv}{L} x100$$

(Equation 7)

Where: Is = sinuosity index (%); L = length of main channel (km); Dv = vector distance of main channel (km)

Time of concentration: it establishes the time required for the entire area of the watershed to contribute to the water flow, and was measured using equation 8 (Kirpich, 1940, cited by Targa, et al., 2012).

$$Tc = 57x\left(\frac{L^3}{H}\right)^{0,385}$$

(Equation 8)

Where: Tc = time of concentration (minutes); L = length of the main channel (km); H = gradient between the highest part and the control section (m).

The parameters river order, density of springs, drainage density and sinuosity index were classified according to the literature (Table 3).

Table 3. Classification of hydrographic features

Parameter	Unit	Limit	Class
Order of the rivers[1]	Units	1-3	Small streams
		4-6	Medium streams
		> 6	Large rivers
Order of the rivers[2]	Units	1	probable fish habitat
		2	Lowhousing conditions
		3	Moderate housing conditions
		≥ 4	High housing conditions
Density of springs[3]	Springs km^{-2}	< 3	Low
		3-7	Medium

		7-15 > 15	High Very high
Drainage density[4]	km km^{-2}	< 0,50 0,50-2,00 2,00-3,50 > 3,50	Low Medium High Very high
Sinuosity index[5]	%	< 20 20-29 30-39 40-50 > 50	Very straight Straight Wandering Winding Very sinuous

Source: [1]Vannote, et al. (1980); [2]Adaptado de Fairfull & Witheridge (2003); [3]Lollo (1995); [4]Beltrame (1994); [5]Romero, Formiga & Marcuzzo (2017)

Stage 4 - Soil cover dynamics

To analyze the dynamics of land cover, we used images recorded by the Landsat 5 (1984) and Landsat 8 (2020) satellites (INPE, 2020). Landsat 8 (2020) (INPE, 2020) was chosen from July to September due to the absence of clouds and better image quality (Table 4).

Table 4. Characteristics of the Landsat 5 and Landsat 8 satellite images used to produce the deforestation index for the Paraíso river basin

				Resolution				
Year	Satellite	Sensor	Band	Spectral (µm)	Space (m)	Radiometric (bits)	Time (days)	Orbit/Point
1984	Landsat 5	TM	3 4 5	0,63-0,69 0,76-0,90 1,55-1,75	30	8	16	230/69
2020	Landsat 8	OLI	4 5 6	0,64-0,67 0,85-0,88 1,57-1,65	30	16	16	230/69

TM = Thematic Mapper; OLI = Operational Land Imager

Land cover is mainly made up of three classes, which are identified as water, agriculture and native forest. These covers were classified using four steps:

Step 1: calculating the normalized difference vegetation index (NDVI), using equation 9.

$$NDVI = (IP - V) / (IP + V) \quad \text{(Equation 9)}$$

Where: IP = Near Infrared (B4 = Landsat 5; B5 = Landsat 8); V = Red (B3 = Landsat 5; B4 = Landsat 8)

Step 2: collecting 15 pixel samples in each land cover class, totaling 45 pixel samples in each NDVI image.

Step 3: dividing the NDVI image into classes using the "slicer" tool, and converting the generated matrix image into vector format using the "polygonize" tool.

Step 4: comparing the classified image with the false color image (R5G4B3 for Landsat 5, and R6G5B4 for Landsat 8) to validate the classification.

Land cover analysis was carried out in the watershed and its riparian zone. The latter was delimited using the "Buffer" tool, considering a 50 m radius for springs and a 30 m margin for rivers, as established by the Brazilian Forest Code (Brazil, 2012).

Stage 5- Drawing up the maps

The "New Print Composer" tool in the QGIS software was used to create the map, and the Geographic Coordinate System and Datum WGS 84 were used as references.

3 Results and discussion

3.1 Geometric characteristics

The watershed has an area of 50.76 km², with perimeter of 49.04 km, shape factor of 0.16, circularity index of 0.27 and compactness coefficient of 1.93. The watershed therefore has an elongated shape and is not susceptible to flooding.

Similar results can be seen in other watersheds that belong to the Guaporé river basin, such as the São Jorge (Pacheco, et al., 2020), Jacuri (Panza, et al., 2020) and Gavião (Donegá, et al., 2021) watersheds.

3.2 Topographical features

Altitude values range from 234 m to 458 m, with an average value of 304 m (Figure 2) and an altimetric range of 224 m. Considering that the region has an average annual temperature of 24° (SEDAM, 2012), and that the temperature drops by 0.44°C for every 100m of vertical rise (Blum, Roderjan & Galvão, 2011), it can be deduced that the micro-basin has a temperature range from 23.01°C to 24.99 °C.

Altitude influences temperature, precipitation and evapotranspiration (Villela & Mattos, 1975), which can be used as an indicator for the pre-selection of agricultural and forestry species of economic interest. Within the altitude range, at least 58 species can be found in the Paraíso river basin, which can be seen in the work of Bourke (2010): avocado (Persea americana), butternut squash (Cucurbita moschata), watercress (Rorippa nasturtium-aquaticum), peanuts (Arachis hypogaea), rice (Oryza sativa), banana (Musa sp.), ata (Annona reticulata), sweet potato (Ipomoea batatas), barberry (Basella alba), broccoli (Brassica oleracea cv. Group Broccoli), cocoa (Theobroma cacao), coffee (Coffea canephora var. robusta), cajamango (Spondias cytherea), cashew (Anacardium occidentale), sugar cane (Saccharum officinarum), lemongrass (Cymbopogon citratus), yam (Dioscorea alata), carambola (Averrhoa carambola), chayote (Sechium edule), coconut (Cocos nucifera), cauliflower (Brassica oleracea cv. Group Cauliflower), beans (Phaseolus vulgaris), breadfruit (Artocarpus altilis), ginger (Zingiber officinale), sunflower (Helianthus annuus), guava (Psidium guajava), soursop (Annona muricata), yam (Dioscorea esculenta), jackfruit (Artocarpus heterophyllus), red raspberry (Syzygium malaccense), orange (Citrus sinensis), lime (Citrus aurantifolia), lemon (Citrus limon), papaya (Carica papaya), castor bean (Ricinus communis), cassava (Manihot esculenta), mango (Mangifera indica), passion fruit (Passiflora quadrangularis), yellow passion fruit (Passiflora edulis f. flavicarpa), watermelon (Citrullus lanatus), melon (Cucumis melo), corn (Zea mays), cucumber (Cucumis sativus), black pepper (Piper nigrum), chili pepper (Capsicum frutescens), bell bell pepper (Capsicum annuum cv. group Grossum), pine cone (Annona squamosa), pitanga (Eugenia uniflora), okra (Abelmoschus esculentus), radish (Raphanus sativus cv. group Small Radish), pomegranate (Punica granatum), parsley (Petroselinum crispum), rubber tree (Hevea brasiliensis), soybean (Glycine max), taioba (Xanthosoma sagittifolium), taro (Colocasia esculenta), tomato (Lycopersicon esculentum) and annatto (Bixa orellana). In view of the above stuation, there is a great potential for the development of agriculture and the financial sustainability of private agricultural establishments in the studied region.

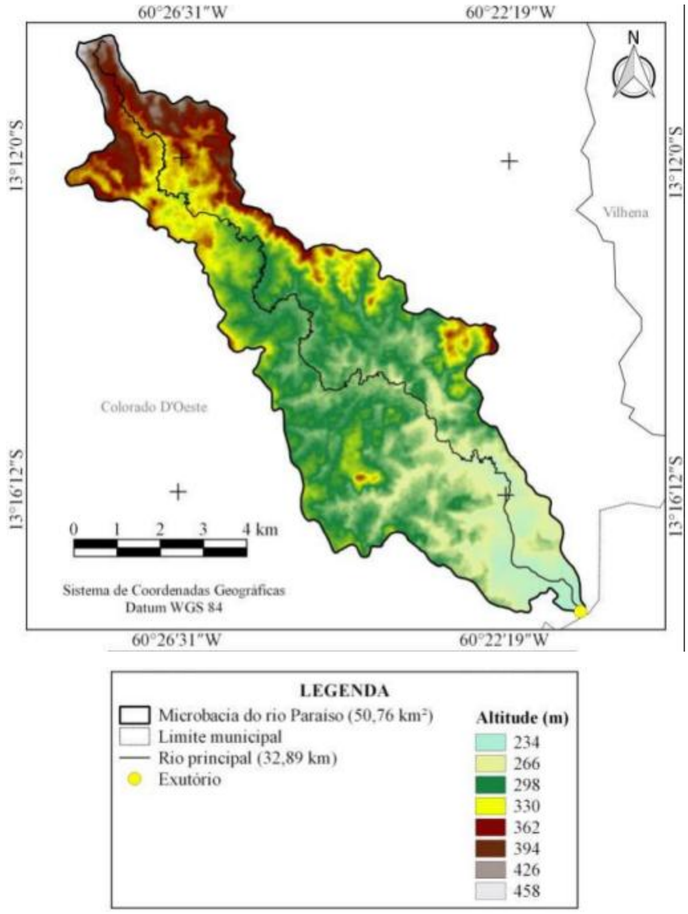

Figure 2. Altitude of the Paraíso river basin, Western Amazonia, Brazil

Source: Authors

The diversity of species of economic interest makes it possible to implement intercropping systems, reducing the financial risk, which is usually linked to market susceptibility in monoculture systems. In a study carried out by Barbosa et al. (2016), for example, it was found that the diversified cultivation system can lead to increases of up to 50% in the producer's income compared to a monoculture coffee system. These same authors report that, in the view of farmers, coffee activity has many risks and low market stability, and this instability can be partly compensated with the diversification of production in the regional market (e.g. the sale of vegetables).

When analyzing the slope of the landscape, it was found that the micro-basin has flat to hilly terrain, with a greater coverage of the wavy (43.64%) and gently wavy (36.54%) classes (Figure 3). The slope of the land influences the speed of surface runoff and, consequently, soil losses due to water erosion (Bertoni & Lombardi Neto, 2014). According to Lepsch et al. (2015), surface runoff is slow to very slow on flat terrain, but the speed of runoff increases as the slope increases, and is considered very fast on steep terrain. Therefore, it is recommended to adopt conservation soil management practices in private agricultural establishments, especially in the steeper regions.

Conservation management practices can be of an edaphic, mechanical or vegetative nature and aim to maintain or improve soil fertility, reduce surface runoff, reduce losses of soil, organic matter and nutrients, encourage water infiltration into the soil, supply the water table and increase crop productivity (Bertoni & Lombardi Neto, 2014). According to Zonta et al. (2012), management practices of an edaphic nature can be classified as liming, fertilization (chemical, organic and green) and fire control, and of a vegetative nature as afforestation, reforestation, grazing, cover crops, contour cultivation, crop rotation, strip planting, alternate weeding, no-till, mulching, weeding and cordons of vegetation, and mechanical terracing. Therefore, there are various types of management that can be combined according to the slope characteristics of each region and the financial conditions of the interested party.

The watershed has regions with different levels of influence on the spread of fires, classified as low, moderate, high, very high and extremely high, covering 78.53%, 16.73%, 3.88%, 0.79% and 0.08% of the total area of the watershed, respectively. The predominance of the low and moderate influence classes on the spread of fires was also observed in other micro-basins located in the state of Rondonia, such as the micro-basins of the Tamarupá (Vendruscolo, et al., 2021), Gavião (Donegá, et al., 2021), Tinguí (Santos, et al., 2019) and Três Galhos (Silva, et al., 2021) rivers. This is a desirable characteristic for private agricultural establishments, as there is less chance of accidental fires causing damage to crops and physical structures.

With regard to the region's potential for agricultural mechanization, it can be seen that the watershed has 24% of its area classified as extremely suitable, 34.20% as very suitable, 20.31% as suitable, 11.47% as moderately suitable, and only 10.03% as not suitable. Similar results were observed in the Alto Rio Escondido (Vendruscolo, et al., 2020a), Médio Rio Escondido (Vendruscolo, et al., 2020b), Gavião (Donegá, et al., 2021), Três Galhos (Silva, et al., 2021), Mutum (Souza, et al., 2021) and Jacuri (Panza et al., 2021), and explain why agribusiness has developed well in the region. The municipalities are among the main soybean producers in the state of Rondonia (Pereira & Kahil, 2010).

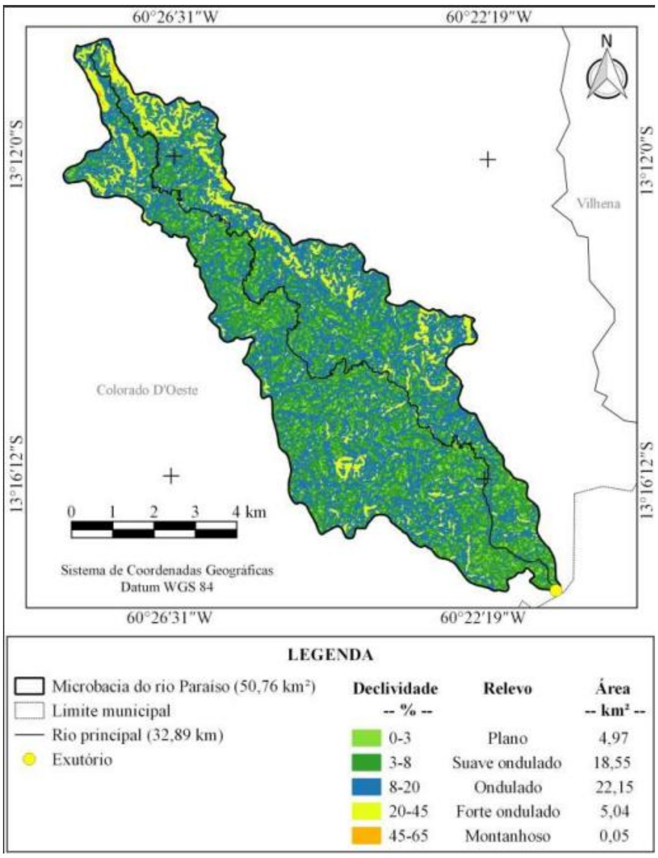

Figure 3. Relief of the Paraíso river basin, Western Amazonia, Brazil

Source: Authors

3.3 Hydrographic characteristics

The Paraíso river basin has a drainage network of 179.37 km, a 5th order dendritic drainage pattern (Figure 4), 9.50 springs km^{-2} (Figure 5), a drainage density of 3.53 km km^{-2}, a maintenance coefficient of 283.0 m² m^{-1} , a sinuosity index of 47.73% and a concentration time of 6.68 h.

Dendritic patterns are very common in the state of Rondonia, which can be seen in the micro-basins Alto Rio Escondido (Vendruscolo, et al., 2020a), Médio Rio Escondido (Vendruscolo, et al., 2020b), Enganado (Moreto, et al., 2019), Jacuri (Panza, et al., 2020), Tinguí (Santos, et al., 2019), Tamarupá (Vendruscolo, et al., 2021) and Manicoré (Vendruscolo, et al., 2019). This type of pattern is formed due to the horizontal homogeneity of the rock (e.g. granite and gneiss) or unconsolidated material, which allows erosion to develop in a similar way in all directions (Earle & Panchuk, 2019).

The number of river orders indicates that the region has a medium-sized river with a high potential for fish habitation (Table 3). The greatest diversity of the aquatic community develops in medium-sized rivers, with 3 to 5 drainage orders, due to the greater variation in temperature (Vannote, et al., 1980), so the Paraíso river basin has interesting hydrographic characteristics that encourage studies of the aquatic ichthyofauna.

The density of springs of 9.50 springs km^{-2} is considered high, while the drainage density of 3.53km km^2 is very high (Table 3), which is observed in the Alto Rio Escondido watershed (Vendruscolo, et al, 2020a), located in the Guaporé river basin. These parameters are directly related to the slope of the landscape (Vendruscolo, et al., 2020a; Vendruscolo, et al., 2020b). Increased slope favors water erosion (Bertoni & Lombardi Neto, 2014), increasing the probability of the formation of channels that tend to deepen to the water table (Guerra, 1997), and consequently the formation of new springs and watercourses. Therefore, these results indicate that the watershed has a high capacity to generate new watercourses and a high water potential, requiring stricter planning to maintain the quantity and quality of water.

The maintenance coefficient of 283.0 m^2 m^{-1} indicates that a larger area is needed to maintain water resources in the Paraíso river basin compared to the Alto Rio Escondido (Vendruscolo, et al., 2020a), Médio Rio Escondido (Vendruscolo, et al., 2020b) and Três Galhos (Silva, et al., 2021) basins, whose values are 234 m^2 m^{-1}, 246 m^2 m^{-1} and 254.5 m^2 m^{-1}, respectively.

The sinuosity index indicates that the main channel is sinuous. This characteristic is very common in regions with dendritic drainage pattern, which can be seen in the micro-basins of the Tinguí (Santos, et al., 2019), Manicoré (Vendruscolo, et al., 2019), Três Galhos (Silva, et al., 2021), Tamarupá (Vendruscolo, et al., 2021) and D'Alincourt (Silva, et al., 2019) rivers. This type of channel has a slower water flow compared to a straight channel (Villela & Mattos, 1975), because it has greater amounts of physical barriers, including woody fragments from marginal vegetation, which accumulate in the meanders, forming microhabitats that are used as shelters against predators by many fish species (Matthews, 2003 apud Silva, Melo & Vênere, 2007). Therefore, studies aim to identify the ichthyofauna in this watershed, in order to better understand the complexity of the region's aquatic ecosystem.

The concentration time in the Paraíso watershed (6.68 h) is higher than that observed in the Mutum river watersheds (1.78 h) (Souza, et al., 2021), Três Galhos (2.28 h) (Silva, et al., 2021) and Gavião (2.74 h) (Donegá, et al., 2021). The difference in concentration time is mainly associated with the length of the main channels, since it has the following orders of magnitude: Mutum (6.52 km) < Três Branchos (12.4 km) < Gavião (26.41 km) < Paraíso (32.89 km).

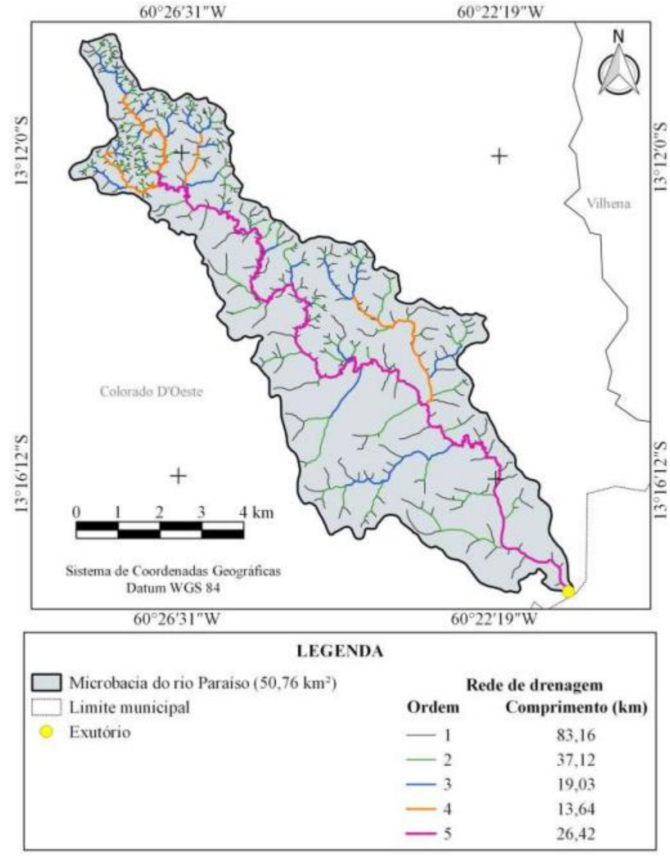

Figure 4. Drainage network and river order in the Paraíso river basin,Western Amazonia, Brazil

Source: Authors

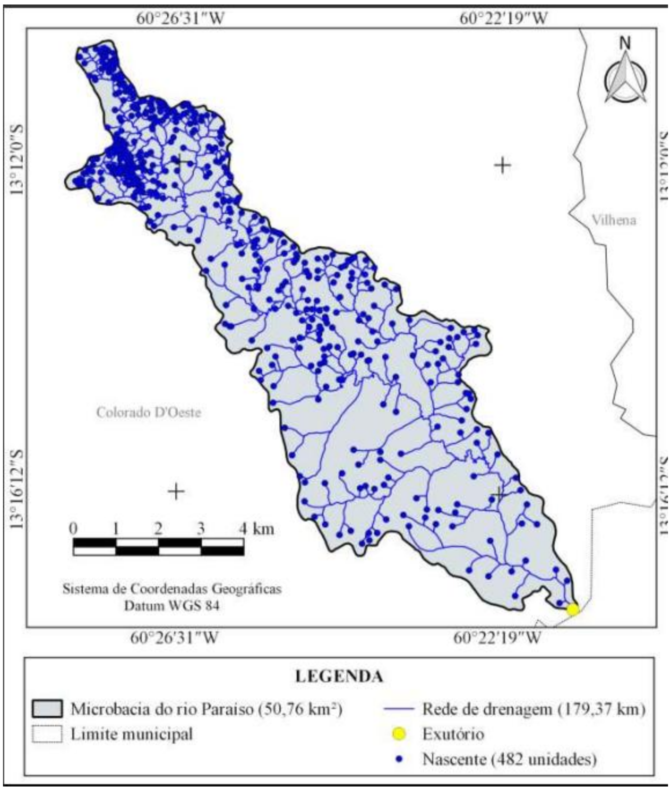

Figure 5. Spatial distribution of springs in the Paraíso river basin, Western Amazonia, Brazil

Source: Authors

3.4 Land cover dynamics in the watershed (1984 and 2020)

Land cover with native forest was reduced over 36 years, both in the watershed and in the riparian zone, leaving only 19.29% and 34.08% of the total area of these regions, respectively (Figures 6 and 7). The main cause of these reductions is associated with agricultural growth in the region. From 1984 to 2020, the micro watershed area in the region increased from 25.06% to 80.32%, while the agricultural growth in the riparian area increased from 20.55% to 64.21% during the same period (Figures 6 and 7).

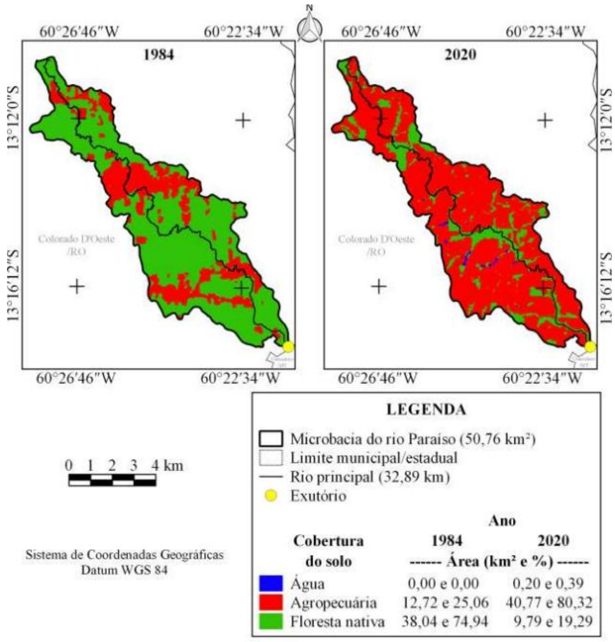

Figure 6. Cover dynamics in the Paraíso micro-basin, Western Amazonia, Brazil, in the years 1984 and 2020

Source: Authors

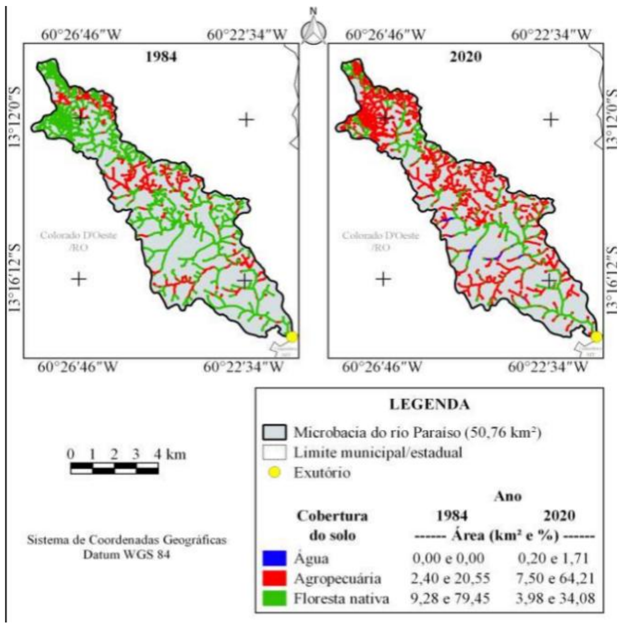

Figure 7. Cover dynamics in the riparian zone of the Paraíso watershed, Western Amazonia, Brazil, in the years 1984 and 2020

Source: Authors

The advance of agriculture over the years has led to economic development in the region, but it should be emphasized that it is necessary to maintain an adequate proportion of native forest in each part of the terrain in order to maintain the quality and availability of water for current and future generations, thus ensuring the sustainable development of the region. In a study carried out by Tambosi et al. (2015), it was found that forest cover has different eco-hydrological functions according to its position on the relief, recharging aquifers at the top of hills, reducing surface runoff and containing water erosion on slopes, protecting water quality in riparian zones and providing auxiliary elements in gaps. Therefore, the maintenance of native forest in permanent preservation areas (PPA) and Legal Reserves (LR), and the inclusion of the tree component in production systems, such as agroforestry, silvopastoral and agroforestry systems, are highly recommended practices for agricultural establishments that make up the Paraíso river basin.

4 Conclusion

The Paraíso River basin is elongated and has low sensitivity to flooding, with elevations ranging from 234 m to 458 m. The terrain is dominated by undulating terrain (43.68%), with medium sized river, 5th order dendritic drainage pattern, high spring density, very high drainage density, meandering main channel, low maintenance coefficient and high concentration time.

In the period from 1984 to 2020, farming and cattle-raising advanced over native forest areas, occupying up to 80.32% of the watershed's area and 64.32% of the riparian zone in the last year.

The characteristics of the landscape of the Paraíso river basin indicate that the region has high potential for the development of agricultural systems, including agricultural mechanization. However, it is recommended to adopt conservationists' soil and water management practices, recover and maintain the native forest in the riparian zone and legal reserves, and integrate the tree component into economic systems through agroforestry, silvopastoral and/or agroforestry systems.

Studies are recommended to analyze the quantity and quality of forest cover in the areas of Legal Reserves, with the aim of complementing the information needed to develop strategies aimed at maintaining the quality and quantity of water resources.

Conflicts of interest

The author declares no conflicts of interest regarding the publication of this paper.

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