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Caracterização morfométrica da Bacia Hidrográfica do Rio Acará (Nordeste Paraense) a partir de dados SRTM

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RESUMO

Atualmente a Amazônia vem sofrendo significativos impactos provenientes de ações antrópicas como a ocupação rural e urbana desordenada, a agropecuária e a mineração. Frente a isso, a Política Nacional de Recursos Hídricos, instituída pela lei nº 9.433 de 8 de janeiro de 1997, apresenta o sistema de administração espacial denominado bacias hidrográficas. Dentre suas aplicabilidades, a bacia hidrográfica é base para o entendimento da dinâmica do ciclo hidrológico e dos impactos ocasionados por atividades humanas. Assim, a utilização de geotecnologias tem-se apresentado como uma promissora alternativa no monitoramento ambiental de bacias hidrográficas. Objetivou-se com este trabalho realizar a caracterização morfométrica da bacia hidrográfica do rio Acará, localizada no nordeste paraense, por meio de dados SRTM. Assim, determinaram-se os índices globais de forma, hierarquia fluvial, hipsometria e declividade da bacia hidrográfica. Diante dos resultados obtidos, infere-se que a Bacia Hidrográfica do Rio Acará possui forma alongada, promovendo menor concentração do deflúvio e menor exposição a grandes enchentes, com hierarquia fluvial de 6ª ordem. Em relação a sua declividade, a bacia enquadra-se, majoritariamente, nas classes plana e suave ondulada, com altitude máxima de 104,47 metros. Assim, a caracterização morfométrica de bacias hidrográficas a partir de dados SRTM mostrou vantagens como velocidade de processamento, melhor integração com dados secundários, replicabilidade e redução de intervenções manuais. Além disso, as informações geradas podem contribuir com a compreensão da dinâmica ambiental da Bacia Hidrográfica do Rio Acará, subsidiando bancos de dados para a otimização de planos de gestão.

Palavras-chave: Amazônia, recursos hídricos, gestão e planejamento, sensoriamento remoto, geoprocessamento.

Morphometric characterization of the Acará River Water Basin (Northeast Pará) through SRTM data

ABSTRACT

Currently, the Amazon has been suffering significant impacts through human actions as rural and urban disordered occupation, agriculture, livestock and mining. In face of this situation, the Hydric Resources National Policy, instituted by law number 9,433 from January 8 of 1997, presents the spatial administration system named water basin. Through its applicability, the water basin is base to understand the dynamic of the hydrologic cycle and of impacts caused by human activities. Thus, the geotechnology use has presented as a promising alternative in environmental monitoring of water basins. This research aims to generate the morphometric characterization of the Acará River Water Basin, localized in northeast Pará, through SRTM data. Thus, was determined the shapes global index, fluvial hierarchy, hypsometry and declivity of the water basin. According to obtained results, is possible to infer that the Acará River Water Basin has an elongated form, promoting less defluvium concentration and less exposure to large-scale flooding, with 6th order of fluvial hierarchy. In relation to declivity, the basin fitted, mostly, in flat and smoothly wavy classes, with maximum altitude of

104.47 meters. Thus, the morphometric characterization of water basins, through SRTM data, presented several advantages such as processing speed, better secondary data integration, replicability and less manual intervention. Besides, the information produced can contribute with the comprehension of the environmental dynamic of the Acará River Water Basin, contributing with database for the optimization of management plans.

Keywords: Amazon, water resources, management and planning, remote sensing, geoprocessing,

Introduction

The Water Resources National Policy, instituted by Law No. 9,433 on January 8, 1997, has as one of its instruments, the information system about water resources. It presents a spatial management system named as water basins. This system is defined as a territorial unit of planning and management which encompasses the drainage network that flows to river outlet connecting to river sources. Also includes water divisors, hydrography and land uses and occupations to promote subsidies for management plans of its natural resources (Brasil, 1997).

According to Tucci (2012), the water basin is key to understanding the hydrological cycle, mainly in its land phase, where it is possible to understand its relationship with other natural and anthropic factors. Thus, the watershed is the foundation of several environment analyses, such as morphometric characterization, as it says Kudnar and Rajasekhar (2020) which describes the morphometry as a tool that supplies a quantitative description of the drainage system from watershed.

Currently the Amazon and its water basins and sub-basin has been suffering from the impact of human activity such as disordered rural and urban occupation, agriculture, livestock and mining performed with inappropriate techniques. These actions lead to environmental impacts as: decreased availability of water resources, deforestation, erosive processes, water quality alterations, etc. (Nascimento and Fernandes, 2017).

According to several authors (Pinto et al., 2018; Venkatesh et al., 2019; Mahala, 2020; Kudnar and Rajasekhar, 2020; Odiji et al., 2021), the importance of the morphometric characterization of water basins stands out in the development of environmental studies, improvement of management plans of natural resources and conservative uses, besides mitigation of environmental impacts caused by atypical natural events. Still according to the same authors, this characterization allows identifying characteristics related to the shape, structural arrangement and drainage network, through linear, aerial and basin parameters, which gives subsidies to a precise analyze of physical aspects of the water basin.

In addition, the morphometric analysis can provide major informations about soil erosive processes by geomorphological evolution stages as it shows the research made by Mahala (2020). Also, Odiji et al. (2021) emphasizes the importance of morphometric characterization in contribute to flood risk data generation.

The geotechnology use has been showed as a promissory alternative in environmental monitoring of water basins, acting as a major optimizing tool. The use of the Digital Elevation Model (DEM) through the remote sensing data of Shuttle Radar Topography Mission (SRTM) shows many advantages in digital resource applications such as processing speed, secondary data integration, replicability and less need for manual intervention, which is reflected by its several use by literature (Venkatesh et al., 2019; Kudnar and Rajasekhar, 2020; Odiji et al., 2021). These advantages are capable of providing products such as basin and drainage network delimitation, declivity, hypsometry and stream direction, which are essential in morphometric characterization of water basins (Valeriano et al., 2006; Oliveira et al., 2010).

Today, the Acará River Water Basin suffers from many environmental impacts from the opening of pasture areas for livestock and the increasing expansion of palm oil cultivation (Dias, 2019). Among the consequences of these activities, what stands out is the loss of biodiversity from forest burning for agricultural activities, the degradation of soil and water bodies, as well as the unlawful occupation of permanent preservation areas (PPA), indigenous areas, human settlements and legal reserves (Souza et al., 2019).

One of the major objectives of the Water Resources State Policy of Pará, Law No. 6,381, July 25, 2001, is to promote the inventory, use, control, and protection of water resources by creating a database to inform decision-making processes and monitoring (Pará, 2001). One of the main initiatives flowing from this policy is the Green Cities Program (serving cities located along the Acará River Water Basin), which sets goals for combating deforestation through policy actions that stimulate forest management, reforestation, sustainable use of deforested land, conservation,

and the recuperation of PPAs and legal reserves – all necessary components of understanding the environmental dynamic provided by morphometric characterization to implement projects and governmental programs (Dias, 2019).

In literature it is observed the deficiency from information about hydrographic and physiographic data from Acará Basin area. Also, it is expected that Acará River Water Basin presents the same pattern from Amazon basins, which means an elongated form with low declivity relief. Besides, the results generated in this paper can be useful in management of water resources, plans and decision-making of the area, as it says the Pará's water resources policy.

Thereby, the objective of this paper is to perform the morphometric characterization of the Acará River Water Basin, located in the northeastern region of the state of Pará, Brazil

through SRTM data processing in the Geographic Information System (GIS).

Material and methods

Study Area

The Acará River Water Basin (ARWB) (Figure 1) is localized in the mesoregion of northeastern Pará (the Eastern Amazon) in the larger hydrographic system of the Guamá River basin. It has an area of 13,536.32 km², encompassing nine cities: Acará, Aurora do Pará, Bujaru, Concórdia do Pará, Ipixuna do Pará, Moju, São Domingos do Capim, Tailândia, and Tomé-Açu. However, the basin is largely nestled between Tomé-Açu, Tailândia, and Acará, which comprises 98 percent of its area.

Figure 1. Map of Acará River Water Basin.

The source of the main river, after which the basin is named, is localized in the city of Tailândia. From there, it is about 383 km to the mouth of the river in the Bay of Guajará, which is located in the city of Belém. The main roads that pass through the basin are the PA-252, PA-256,

PA-140, and PA-150. Also, the area of the basin encompasses fifteen human settlements and two indigenous areas.

According to Koppen-Geiger (1936) classification, the Acará River Water Basin contains two climates type: Af (Equatorial tropical)

and *Am* (Monsoon tropical). An *Af* climate is hot and wet and has no dry season. The temperature ranges from around 22°C in the hot months to 18°C in the cold months, with more than 60 mm of rain in the "dry" months. An *Am* climate has similar characteristics but with dry winters and rains of more than 2,500 mm per year.

SRTM data processing

First, was acquired the Digital Elevation Model (DEM) from the Shuttle Radar Topography

Mission (SRTM) of the United States Geological Survey (USGS) available from the TOPODATA project, which is the geomorphometric database of Brazil (<http://www.dsr.inpe.br/topodata/>). The scene codes used for Acará River Water Basin (ARWB) are 01S495, 01S48_, 02S495, 02S48_, 03S48_ and 03S495 (Figure 2). After this was made a mosaic of the scenes and then reprojected to SIRGAS 2000 UTM 22 S coordinate system.

Figure 2. DEM mosaic and scenes codes by TOPODATA used in the morphometric characterization of ARWB.

The automatic delimitation of the water basin was developed in the software Qgis 3.6.2 with tools set available in the GIS, which were GRASS 7.6.1 and SAGA (Automated Geoscientific Analysis System). The methodology

used in the water basin delimitation and hydrographic definition was based in Costa et al. (2020). From DEM obtaining to the maps confection, was used the following algorithms exposed in Table 1.

Table 1. Algorithms used in SRTM data processing for the water basin delimitation and hydrographic network.

Algorithms	Description
Fill sinks	It fills the sinks caused by radar reading errors due to water bodies and rugged reliefs. To the filling it takes into account the neighboring pixel altitudes.
r.watershed	Generates the water flow direction, drainage network and the water sub-basin delimitation from the scene.
r.water.outlet	Determines the water basin limit from its river outlet.
Strahler order	Determines the order of the drainage network according to Strahler (1957) method.

The order of the algorithm's use in the DEM process is illustrated in the flowchart exposed in Figure 3.

Figure 3. Flowchart of the major steps realized in delimitation of water basin, drainage network, declivity and hypsometry.

After the water basin limit determination came the vectorization of raster data through *r.to.vect* command for better optimization of the following processes. After this, the ordered hydrography according to Strahler (1957) was set by *Strahler order* command and then vectorized.

After the fill sinks step, the DEM (Digital Elevation Model) was used to generate the declivity map, given in percentage unit according to EMBRAPA (2006) pattern, which sets: for flat

lands the range of 0 to 3 percent inclination; for smoothly wavy lands the range of 3 to 8 percent inclination; for wavy lands the range of 8 to 20 percent inclination; for strongly wavy lands the range of 20 to 45 percent inclination; for mountainous lands the range of 45 to 75 percent inclination and for steep lands higher than 75 percent inclination. The reclassification according to EMBRAPA pattern was made using the command *r.recode*.

The hypsometric map was made through a fill sinks command with the rendering type as simple band false-color, classified in meters.

Morphometric Analysis

After the SRTM data processing, was set the physical parameters of water basin such as: area, perimeter, main river length, channel quantities, channel length, channel mean length, drainage pattern, form factor, circularity ratio,

Sinuosity ratio, compactness coefficient, drainage density, rivers density, declivity, altitude and water course order.

The processes realized for parameters determination was made in software Qgis 3.6.2 with the use of an electronic spreadsheet program for data organization.

In Table 2 it is possible to observe the morphometric parameters calculated with its measure units, limits, classes and references.

Table 2 - References values for morphometric parameters characterization.

Parameters	Units	Limits	Classes	References
Order (Strahler)	-	-	Water courses with just one segment are considered 1 st order. The union of two 1 st order segments generates a 2 nd order course and so on.	Strahler (1957)
Form Factor (F_F)	-	< 0,50 0,51 - 0,75 0,76 - 1,00	No exposure to floods Medium exposure to floods High exposure to floods	Horton (1945)
Compactness Coefficient (K_C)	-	1,00 - 1,25 1,26 - 1,50 > 1,50	High propensity for big floods Medium propensity for big floods No propensity for big floods	Villela e Mattos (1975)
Circularity ratio (R_C)	-	0,36 - 0,50 0,51 - 0,75 0,76 - 1,00	Elongated form Intermediary form Circular form	Strahler (1964)
Drainage Density (D_D)	Km/Km ²	< 0,50 0,51 - 2,00 2,01 - 3,50 > 3,50	Low Medium High Very high	Horton (1945)
Rivers Density (D_R)	Channels/Km ²	< 1,00 1,01 - 2,00 > 2,00	Low capacity for new channel generation Medium capacity for new channel generation High capacity new channel generation	Horton (1945)
Sinuosity ratio (R_S)	%			Schumm (1963)

< 20	Very Straight
21 - 29	Straight
30 - 39,9	Rambling
40 - 49,9	Winding
> 50	Very Winding

In table 3 it is possible to observe the formulas used in each morphometric parameter calculation.

Table 3. Morphometric parameters and its formulas.

Parameter	Formulas
Form factor (F_F)	$F = \frac{A}{L^2}$ Where: F_F - Form factor; A - Basin area (km ²); L - Basin length (km).
Compactness coefficient (K_C)	$Ck = 0,28 \frac{P}{\sqrt{A}}$ Where: K_C - Compactness coefficient; P - Basin perimeter (km); A - Basin area (km ²).
Circularity ratio (R_C)	$Ci = \frac{12,57A}{P^2}$ Where: R_C - Circularity ratio; P - Basin perimeter (km); A - Basin area (km ²).
Drainage density (D_D)	$Dd = \frac{Lc}{A}$ Where: D_D - Drainage density; Lc - Total length of all channels; A - Basin area (km ²).
Rivers density (D_R)	$Rd = \frac{Nc}{A}$ Where: D_R - Rivers density; Nc - Channels quantity; A - Basin area (km ²)
Sinuosity ratio (R_S)	$Si = 100 \left[\frac{(L - Dv)}{L} \right]$ Where: R_S - Sinuosity ratio (%); L - Main river length (Km); Dv - vector length of main river (km).

Source: Author, 2020.

Results and Discussion

In Table 4 it is possible to observe the results of morphometric parameters calculated for the Acará River Water Basin.

Table 4. Morphometric parameters of the Acará River Water Basin, PA.

Parameters	Results
Area (Km ²)	13,536.32
Perimeter (Km)	1,461.14
Basin axis (Km)	214.43
Main river length (Km)	383.01
Total length of channels (Km)	6,333
Mean length of channels (Km)	2.16
Quantity of channels	2,920
Order	6 th

River density (D_R) (Channels/Km ²)	0.21
Form factor (F_F)	0.29
Compactness coefficient (K_C)	3.51
Circularity ratio (R_C)	0.08
Drainage density (D_D)	0.46
Sinuosity ratio (R_S)	44.01

The basin area obtained through SRTM data was 13,536.32 km² and the main river length was 383.01 km. These values are consistent with those calculated by the Agência Nacional de Águas (ANA), showing only a small difference. According to ANA, the ARWB has an area of 13,537.5 km² and a main river length of 398.7 km (Dias, 2019).

Through DEM processing was obtained 1,461.14 km of perimeter, which is the distance of the external line that delimitates the basin area. Also, it was accounted 2,920 channels in basin area that sums 6,333 km and the mean length of all channels of the basin was 2.16 km.

The form factor (F_F) is a parameter that indicates the flood susceptibility in a water basin, when closer to 1.00 more rounded will be the basin form and bigger will be its vulnerability. The F_F value obtained for ARWB was 0.29, indicating that the basin is not exposed to big floods.

The compactness coefficient (K_C) is another indicator that shows the susceptibility of a water basin to large-scale flooding, which values next or above 1.5 indicates elongated form and minimal chances to floods. For ARWB the K_C value was 3.51, which means that the basin shows an elongated form with no occurrence of flooding.

Another important form parameter is the circularity ratio (R_C), which indicates an elongated basin form trend for values below than 0.51, and more rounded basin form for values next to 1.0, favoring flood processes. For ARWB, the result of R_C was 0.08, which indicates a very elongated basin form, corroborating with F_F and K_C results.

A research made by Mahala (2019) presented the value of 0.45 of F_F for the Kosi basin, in India, which indicates a near-circular shape and a high peak flow in specific periods. The author emphasizes the advantage of elongated basins in management of floods and resources than the circular basins. On the other hand, Odiji et al. (2021) obtained a value of 0.02 for F_F , which indicates elongated shape and low peak flow with longer duration.

In a study made by Kudnar and Rajasekhar (2020) in Wainganga water basin, India, the

authors found 0.38 for R_C , which indicates that the basin tends to have a circular shape. According to the authors, this parameter can indicate the age stage of the tributaries, which low values indicates youth stage, medium values indicates mature stage and high values indicates older stages.

However, a similar result of R_C was obtained by Odiji et al. (2021) in Benue River, Cameroon, with a value of 0.048. According to the authors, low values of R_C can be associated with highly permeable and homogeneous soil.

Similar results were found in a study by Lorenzon (2015), which verified low flood susceptibility in the Benevente water basin in the state of Espírito Santo, which observed values of F_F (0.17), K_C (2.35) and R_C (0.18).

A study made by Félix and Souza (2017) found an elongated form, which means low chances to occur floods events in the Cabaçal river water basin, in the state of Mato Grosso. The facts are evidenced by results of F_F (0.24), K_C (3.39) and R_C (0.08). These results are very similar to those obtained from the Acará River Water Basin.

The drainage density (D_D) is a parameter that indicates the degree of the development of drainage network in a water basin, through the relationship between total channel length (both permanents and temporaries) and drainage area. Values below 0.5 km/km² indicate a weak development and values above 3.50 km/km² is assigned a strong developed drainage network. The result for ARWB was 0.46 km/km², evidencing a weak development degree of its drainage network. Simultaneously, the river density (D_R) for ARWB was 0.21 channels/km², which indicates low potential to generate new channels. Only values above 2.00 channels/km² are assigned a high potential of new channel generation.

Odiji et al. (2021) found similar value of 0.21 km/km² for D_D for the Benue river watershed, which indicates a low value associated with low potential for surface runoff and high infiltration capacity. Still according to the authors, a low value for D_D can indicate the presence of dense vegetation and permeable rocks with low reliefs,

such as in AWRB. Also, high values of D_D demand attention for its susceptibility to flood.

A study by Costa et al. (2020) in the Paraguai/Jauquara water basin in the state of Mato Grosso, observed values of 0.90 km/km² for D_D and 0.72 channels/km² for D_R , with 16,482 km² basin area, which are similar values when compared with the results obtained in ARWB. According to the authors, low values of D_D are related to flat and smooth relief areas with soils showing a high capacity for permeability and erosion resistance, which contributes to a progressive surface runoff. Besides, low values of D_R demand attention for its interference potential in maintenance degree of basin drainage network.

Lastly, the Sinuosity ratio (R_S) is a parameter that indicates the sinuosity of the main river in percentage, and it is related to the bigger or

smaller hydric flow speed in external portions of intricacies, in which values below than 20 percent are considered very straight and values above 50 percent are considered very winding. The value obtained for ARWB was 44.09 percent, indicating a winding main river sinuosity.

A study by Vendruscolo et al. (2020) obtained a R_S of 47.26 percent from the main river of the Médio Rio Escondido water basin in the state of Rondônia, which evidences a bigger hydric flow and sediment accumulation potential over the river. This parameter has a strong interdependence with ground relief, and sinuosity rivers are more recurrent in flat relief areas (Mota et al., 2013; Vendruscolo et al., 2020).

In Figure 3 it is possible to observe the hydrographic network order of ARWB.

Figure 3. Hydrographic network order of ARWB.

The Strahler (1957) hierarchy analysis describes the ARWB as 6th order, since the highest stream order regards the order of the whole basin, giving it an efficient drainage system, for the more branched the drainage network is the more efficient it will be. Its drainage pattern is classified as dendritic or arborescent for showing hydrographic pattern as a tree canopy.

Observing Figure 3 it is possible to infer that 1st order streams are much more numerous, have short length and emerge from highest areas, while 5th and 6th streams are less numerous, lengthly and emerge to valley areas. Studies made by different authors presented the same behavior, where the increase of the stream order follows the decrease of the number of streams is associated

with the conditions of structure and physiographic of the area (Mahala, 2019; Resmi, 2019; Odiji et al., 2021).

From the map illustrated in Figure 3 it is possible to observe the presence of three 5th order rivers. The first is an extensive one in west portion, that encompasses both Tailândia and Acará city, and the others are two short ones in east portion, which gives birth to the main 6th order river. Also the drainage direction of the basin flows from the south, where it is concentrated 1st order streams, to the north, where is localized the outlet of the main 6th order river.

According to Junior and Rossete (2005) this drainage pattern is associated with the presence of channels over the main flow, with the formation of acute angles, and the possible presence of homogenous soils and sedimentary rocks.

In a study made by Mahala (2019) in India, the author explain that high numbers of low order streams in high ground areas can indicate young topography. Also, high quantities of 1st, 2nd and 3rd streams can provide the increase of the drainage network by water flux contribution in lower areas of the basin.

Additionally, Santos et al. (2012) shows the importance of water capitation spots for supply to the Perdizes and Fojo water basin in the state of São Paulo, localized in well drained basin portions, which means bigger order portions. Thus, this necessity is reflected in urban expansion inside water basins as showed by the research of Sampaio et al. (2016), which observed the urban consolidation in both margins of main river from Ribeirão das Vargens de Caldas water sub-basin in the state of Minas Gerais.

Still observing Figure 3, it is possible to infer that a similar behaviour occurs in ARWB,

specifically in the cities of Acará and Tomé-Açu, reflected in locations of both urban headquarters in margins of high orders rivers.

However, this does not occur in the city of Tailândia, where the urban headquarters is located near to 1st order channels of the basin, in higher altitude areas. According to Sampaio et al. (2016), disturbances in higher altitude areas can cause negative impacts in downstream areas, such as the depositing of urban residues. Besides, the urbanization process causes soil waterproofing through paving constructions, causing surface runoff intensification, erosion, and silting up processes, which can decrease the drainage network efficiency from the water basin (Costa, 2016).

Simultaneously, according to the Pará statistic yearbook produced by Fundação Amazônia de Amparo a Pesquisas e Estudos do Pará (FAPESPA) (2019) the population of the city of Acará increased from 54,047 inhabitants in 2014 to 55,513 inhabitants in 2018. Similarly, the population of Tomé-Açu grew from 59,795 inhabitants in 2014 to 62,854 inhabitants in 2018. The population growth in the city of Tailândia was even more drastic, as it increased from 93,906 to 103,664 inhabitants during the same time span, which is a source of concern due to the higher demographic density and quantity. This population increase has considerable potential to exert a more significant impact on natural resources due to the city's proximity to 1st order channels.

In Figure 4 it is possible to observe the declivity map of the Acará basin, expressed in percentage according to a stipulated pattern by EMBRAPA (2006).

Figure 4. Declivity map of Acará River Water Basin.

The mean declivity observed for ARWB was 1.84 percent of inclination, classifying the terrain as flat, and its maximum declivity was 21.57

percent of inclination, with the relief classified as strongly wavy. In Table 5 it is possible to observe each class distribution over the basin area.

Table 5. Declivity class distribution over Acará River Water Basin.

Declivity (%)	Relief	Area (%)
0 - 3	Flat	58.57
3 - 8	Smoothly Wavy	32.54
8 - 20	Wavy	8.72
20 - 45	Strongly wavy	0.14

Source: Author, 2020.

Analyzing Figure 4 and Table 5 it is possible to observe that the relief declivity of ARWB contemplates only until strongly wavy class (20-45 percent of declivity), with the ground mostly framed to flat and smoothly wavy classes, representing 58.57 percent and 32.54 percent of total area respectively. Besides this, it is possible to infer that the basin declivity is homogeneously distributed over its area, although the ARWB presents a considerably extensive drainage area.

The importance in the information obtaining about water basin declivity is related to the management and planning of natural resources according to the water law. It is also relevant to the knowledge about the performance in water distribution between surface and underground runoff (Tonello, 2006; Miotto et al., 2014; Mahala, 2019).

Also, the declivity acts as a major component in landscape characterization,

influencing in the relation between rain and defluvium. That relationship indicates the intensity of impact processes as surface runoff and water infiltration. Thus, declivities with high inclinations (Strongly wavy relief) are more susceptible to suffer with the impacts of the raindrops, which cause removal process in the surface portion of the soil, as known as erosive processes (Costa et al., 2019; Vale and Bordalo, 2020).

According to Vendruscolo et al. (2020) and Cogo, Leven and Schwarz (2003) the relief is related to soil and water loss in the ecosystem; thus, basins that present low values of declivity are less exposed to soil and water loss by hydric erosion.

In a study made by Ribeiro et al. (2008), the authors observed a relation between fire dissemination and area relief, which increases directly with relief declivity, where for relief less than 15 percent the dissemination is considered weak, from 16 to 25 percent moderate, from 26 to 35 percent high, from 36 to 45 percent very high

and for more than 45 percent extremely high. In this way, it is possible to infer that the ARWB presents 91.11 percent of its area with low fire propagation potential.

Additionally, in a study by Höfig and Araujo-Junior (2015) the authors observed a relation between relief declivity and agricultural mechanization, which is inversely proportional to the relief elevation, where values with a rate of 0 to 5 percent inclination is considered extremely able, from 5.1 to 10 percent very able, from 10.1 to 15 percent able, from 15.1 to 20 percent moderately able and for values above than 20 percent mechanization is not recommended. Thus, it is possible to infer that the ARWB presents 91.11 percent of its area varying from extremely able to very able for agricultural mechanization, which is reflected in the intensive monoculture of oil palm in the area (Dias, 2019).

In Figure 5 it is possible to observe the hypsometric map of the Acará River Water Basin.

Figure 5. Hypsometric map of Acará River Water Basin.

According to the map in Figure 5, it is possible to observe that the values of altitude varied in a rate of 0.44 meters to 104.47 meters, with a mean of 52.46 meters and an altimetric amplitude of 104.03 meters.

Also, it is possible to observe that the high altitude areas are concentrated in the south portion of the basin, where is localized parts of Tailândia and Tomé-Açu cities. Concomitantly, low altitude areas are localized in the north portion of the basin,

near to the river outlet, encompassing Acará city. The lower altitudes areas (0.44 – 10 m) expressed in blue, represents water bodies.

In high altitude areas are concentrated the river's source and in the low altitude spots there is the mouth of the river. Thus, the altimetric amplitude guides the drainage direction.

In a study made by Dias (2019) about altitude, also in the ARWB, the author obtained 103 meters of maximum quota, 5 meter of minimum quota, a mean of 51.34 meters, and an altimetric amplitude of 98 meters. Thus, the results obtained through this research are in line with expectations, featuring the ARWB as a low-altitude water basin.

The altitude is characterized by the vector distance between a terrestrial surface spot and the sea level, and it is directly related to the radiation quantity in which the water basin is exposed, influencing natural processes such as evapotranspiration, temperature and precipitation. That way, low altitude areas are more exposed to solar radiation (Pinto et al., 2018).

An altitude variation of 150 meters can cause a temperature variation of up to 1°C (Celsius), which affects evaporation and transpiration. Annual precipitations variations are also more commonly expressed in low altitudes, bringing consequences over medium defluvium and concentration time (Villela and Mattos, 1975; Woodcock, 1976; Silva et al., 2013).

The temperature is lower in high altitude spots, which demands a smaller amount of energy for water evaporation. With this scenario, the pluviometric precipitation stands out in relation to evapotranspiration, that causes an excess of water and, consequently, the rain fall, which supplies the water basin and the maintenance of the flow of water courses and sources (Silva and Tonello, 2014; Nobre et al., 2019).

Several authors found a considerable palm oil monoculture expansion in the central region of ARWB (Gurgel et al., 2017; Dias, 2019; Santos et al., 2019), specifically in areas of medium altitude, and livestock expansion near to the high altitude areas. Additionally, the authors emphasized that the occupation of palm oil and pasture areas tend to take place near to the river's sources, or in other words, along 1st order channels. This can disturb the maintenance of natural resources in water basins as fertilizers and pesticides alter the water quality by running across drainage network. Also, the expansion of livestock can also cause soil compaction from cattle stepping, which negatively

influences soil infiltration and intensifies surface runoff (Costa and Silva, 2016).

At the same time, data from the statistic yearbook of Pará demonstrates that the ARWB contained about 50 percent of all palm oil production in the state of Pará between 2014 and 2017. The city of Tailândia leads in the production of coconut curls among the water basin cities, with about 405,055 tons of coconut curls per year. The whole water basin area produces about 750,000 tons of coconut curls per year, representing about R\$ 180 million (FAPESPA, 2019).

Also, livestock data shows that cattle pasture is a strongly activity in the ARWB, which evolved from 104,533 cattle head in 2013 to 195,362 cattle head in 2016 in the whole water basin area (FAPESPA, 2019). Thus, the information presented by the statistic yearbook of Pará is compatible with the data from the literature mentioned previously about impacts caused by palm oil monoculture expansion and the opening of pasture areas in the ARWB.

Conclusions

This paper generated the morphometric characterization of Acará River Water Basin through Digital Elevation Model (DEM), by making products as maps of strahler order, declivity and hypsometry, and also creating a database of morphometrics parameters as river density, form factor, compactness coefficient, circularity ratio, drainage density and Sinuosity ratio.

According to the results gathered about form factor (F_F), compactness coefficient (K_C), and circularity ratio (R_C) it is possible to infer that the ARWB has an elongated form, promoting low defluvium concentration and not prone to major flooding. Those results are reflected in absence of reported cases of floods in the ARWB.

From the drainage density results, it is possible to verify that the ARWB has low development of its drainage network. Together with the river density (D_R) value obtained, this also evidences weak potential for new channel creation. Additionally, the ARWB's 6th order drainage network has a hydrographic pattern considered dendritic or arborescent as it is very branched.

From Strahler order it was possible to identify areas of low orders as 1st, 2nd and 3rd, as well as high order streams, as 5th and 6th, spotting PPA's and well drained areas from the basin.

The relief declivity presented to the ARWB is predominantly classified as flat and

smooth giving it low propensity to soil and water loss for hydric erosion, favoring soil infiltration.

The mean altitude calculated for the ARWB was 52.46 meters, which is considered to be a low altitude basin, giving it bigger solar radiation exposure.

According to results obtained by this research, it is possible to conclude that the SRTM data used in water basin morphometric characterization is extremely useful, showing several advantages as process speed, bigger precision and high potential to replicability, more interaction with second data and the need for less human intervention.

Furthermore, the information generated in this research has potential to contribute with management plans, natural resource management and area monitoring, especially water resources, as provided by the Water Resources State Policy of Pará. It also can be addicted to the regional database of water basins to be used by government organs and academic community.

Lastly, future studies of use and land cover can be merged to the information generated in this research for a better comprehension of the environmental and socioeconomic dynamic of the Acará River Water Basin.

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Bibliographic references

Brasil, 1997. Lei nº 9433, de 8 de janeiro.
 Cogo, N. P., Levien, R., Schwarz, R. A., 2003. Perdas de solo e água por erosão hídrica influenciadas por métodos de preparo, classes de declive e níveis de fertilidade do solo. *Revista Brasileira de Ciência do Solo* 27, 743-753.
 Costa, F. P. L. D. R., 2016. Plano de recuperação da Área de Preservação Permanente (APP) da nascente do córrego Pipa no município de Aparecida de Goiânia–Goiás. Tese (especialização). Fortaleza, Instituto Federal de Educação, Ciência e Tecnologia.
 Costa, A. A. D., Santos G., E. A., Silva N., S. M. A., 2020. Análise morfométrica da bacia

hidrográfica Paraguai/Jauquara, Mato Grosso-Brasil. *Geosul* 35, 483-500.
 Costa, D. P., Vendruscolo, J., Rosa, D. M., Mendes, D. M., Cavalheiro, W. C. S., Rodrigues, A. A. M., 2019. Morfometria e dinâmica de desmatamento da microbacia Canaã, Amazônia, Brasil. *Brazilian Journal of Development* 5, 30754-30772.
 Costa, P. L. D. C. V., Silva A. A. A., 2016. Resistência à penetração em Latossolo sob floresta ripária e submetido ao pisoteio animal. *Ambiente & Água-An Interdisciplinary Journal of Applied Science* 11, 1109-1118.
 Dias, F. G., 2019. Análise integrada da paisagem na bacia hidrográfica do rio Acará, Amazônia Oriental: subsídios ao planejamento ambiental. 2019. Tese (Mestrado). Belém, Universidade Federal do Pará.
 EMBRAPA. Empresa Brasileira De Pesquisa, 2006. Centro Nacional de Pesquisa de Solos. Manual de métodos de análise de solo. Belém.
 FAPESPA. Fundação Amazônia de Amparo a Estudos e Pesquisas, 2019. Anuário Estatístico do Pará. Belém. Disponível em: <http://www.fapespa.pa.gov.br/anuario_estatistico/demo.html>. Access in: jul 17. 2020.
 Félix, E. A., Souza, C. A., 2017. Levantamento e análise morfométrica da bacia hidrográfica do Rio Cabaçal-MT. *Os Desafios da Geografia Física na Fronteira do Conhecimento* 1, 75-86.
 Gurgel, R. S., Farias, P. R. S., Oliveira, S. N., 2017. Land use and land cover mapping and identification of missuse in the permanent preservation areas in the Tailândia Municipality–PA. *Semina: Ciências Agrárias* 38, 1145-1159.
 Höfig, P., Araujo-Junior, C. F., 2015. Classes de declividade do terreno e potencial para mecanização no Estado do Paraná. *Coffee Science* 10, 195-203.
 Horton, R. E., 1945. Erosional development of streams and their drainage basins; hydrophysical approach to quantitative morphology. *Geological society of America bulletin* 56, 275-370.
 Junior, O. B. P., Rossete, A. N., 2005. Caracterização morfométrica da bacia hidrográfica do ribeirão Cachoeira, MT-Brasil. *Geoambiente on-line* 4, 01-16.
 Koppen, W., Geiger, R., 1936. *Handbuch der Klimatologie. Gebu'der Borntra'ger* 1, 1-44.
 Kudnar, N. S., Rajasekhar, M., 2020. A study of the morphometric analysis and cycle of erosion in

- Waingangā Basin, India. *Modeling Earth Systems and Environment* 6, 311-327.
- Lorenzon, A. S., Fraga, M. D. S., Moreira, A. R., Uliana, E. M., Silva, D. D. D., Ribeiro, C. A. A. S., Borges, A. C., 2015. Influência das características morfométricas da bacia hidrográfica do rio Benevente nas enchentes no município de Alfredo Chaves-ES. *Revista Ambiente & Água* 10, 195-206.
- Mahala, A., 2020. The significance of morphometric analysis to understand the hydrological and morphological characteristics in two different morpho-climatic settings. *Applied Water Science* 10, 1-16.
- Mioto, C. L., Ribeiro, V. O., Souza, D. M. Q., Pereira, T. V., Anache, J. A. A., Paranhos Filho, A. C., 2014. Morfometria de bacias hidrográficas através de SIGs livres e gratuitos. *Anuário do Instituto de Geociências* 37, 16-22.
- Mota, A. A., Grison, F., Kobiyama, M., 2013. Relação entre sinuosidade e índices topográficos na zona topográfica fluvial. *Revista Geonorte* 4, 42-60.
- Nascimento, T. V., Fernandes, L. L., 2017. Mapeamento de uso e ocupação do solo em uma pequena bacia hidrográfica da Amazônia. *Ciência e Natura* 39, 169-177.
- Nobre, N. C., da Silva, C. M., Santana, J. S., da Silva, W. A., 2019. Caracterização morfométrica, climática e de uso do solo da Bacia hidrográfica do rio Farinha-MA. *Acta Iguazu* 9, 11-34.
- Odiji, C. A., Aderoju, O. M., Eta, J. B., Shehu, I., Mai-Bukar, A., Onuoha, H., 2021. Morphometric analysis and prioritization of upper Benue River watershed, Northern Nigeria. *Applied Water Science* 11, 1-28.
- Oliveira, P. T., Alves Sobrinho, T., Steffen, J. L., Rodrigues, D. B., 2010. Caracterização morfométrica de bacias hidrográficas através de dados SRTM. *Revista Brasileira de Engenharia Agrícola e Ambiental* 14, 819-825.
- Pará, 2001. Lei nº 6381, de 25 de julho.
- Pinto, V. R., Pierangeli, M. A. P., de Souza, C. A., Neves, S. S. M. A., Silva, C. J., 2018. Morfometria da Bacia Hidrográfica do Rio Sararé, Sudoeste de Mato Grosso. *Revista Brasileira de Geografia Física* 11, 1721-1731.
- Resmi B. C., Achyuthan, H., 2019. Quantitative analysis of the drainage and morphometric characteristics of the Palar River basin, Southern Peninsular India; using bAd calculator (bearing azimuth and drainage) and GIS. *Geology, Ecology, and Landscapes* 3, 295-307.
- <https://doi.org/10.1080/24749508.2018.1563750>
- Ribeiro, L., Koproski, P. L., Stolle, L., Lingnau, C., Soares, R. V., Batista, A. C., 2008. Zoneamento de riscos de incêndios florestais para a Fazenda Experimental do Canguiri, Pinhais (PR). *Revista Floresta* 38, 561-572.
- Sampaio, O. M. F., Guidi, M. E., Santos, C. A., 2016. Análise morfométrica e revitalização da bacia hidrográfica do Ribeirão das Vargens de Caldas, Poços de Caldas-MG: uma contribuição ao planejamento urbano. *Revista Interface* 11, 232-255.
- Santos, A. M. D., Targa, M. D. S., Batista, G. T., Dias, N. W., 2012. Análise morfométrica das sub-bacias hidrográficas Perdizes e Fojo no município de Campos do Jordão, SP, Brasil. *Revista Ambiente & Água* 7, 195-211.
- Santos, L. S., Nahum, J. S., Santos, C. B., Júnior, S. O. M., 2019. Paisagem rural da microrregião de Tomé-Açu sob a ótica bertrandiana. *Revista Brasileira de Geografia Física* 12, 2694-2715.
- Schumm, S. A., 1963. Sinuosity of alluvial rivers on the Great Plains. *Geological Society of America Bulletin* 74, 1089-1100.
- Silva C. E. B., Silva, C. L., Silva, M. L., 2013. Caracterização física de bacias hidrográficas na região de Manaus-AM. *Caminhos de Geografia* 14, 93-100.
- Silva, J. L., Tonello, K. C., 2014. Morfometria da bacia hidrográfica do Ribeirão dos Pinheirinhos, Brotas – SP. *Irriga* 19, 103-114.
- Souza, R. R. N., Viana, L. S., Júnior, A. P., 2019. Avaliação de Impacto Ambiental na Dendeicultura e Agricultura Familiar no município de Acará-Pará (Brasil). *Revista Brasileira de Meio Ambiente* 5, 14-38.
- Strahler, A. N., 1957. Quantitative analysis of watershed geomorphology. *Eos, Transactions American Geophysical Union* 38, 913-920.
- Strahler, A. N., 1964. *Handbook of Applied Hydrology*. McGraw-Hill, New York.
- Tonello, K. C., Dias, H. C. T., Souza, A. L. D., Ribeiro, C. A. A. S., Leite, F. P., 2006. Morfometria da bacia hidrográfica da Cachoeira das Pombas, Guanhães-MG. *Revista Árvore* 30, 849-857.
- Tucci, C. E., 2012. *Hidrologia: ciência e aplicação*, 4 ed. UFRGS, São Paulo.
- Vale, J. R. B., Bordalo, C. A. L., 2020. Caracterização morfométrica e do uso e cobertura da terra da bacia hidrográfica do rio Apeú, Amazônia oriental. *Formação (Online)* 27, 313-335.

- Valeriano, M. M., Kuplich, T. M., Storino, M., Amaral, B. D., Mendes Jr, J. N., Lima, D. J., 2006. Modeling small watersheds in Brazilian Amazonia with shuttle radar topographic mission-90 m data. *Computers & geosciences* 32, 1169-1181.
- Vendruscolo, J., Pacheco, F. M. P., Rodrigues, A. A. M., de Freitas Ramos, H., Rosa, D. M., Cavaleiro, W. C. S., 2020. Características morfométricas da microbacia do Médio Rio Escondido, Amazônia Ocidental, Brasil. *Brazilian Journal of Development* 6, 565-585.
- Venkatesh, M., 2019. A GIS-based assessment of recent changes in drainage and morphometry of Betwa River basin and sub-basins, Central India. *Applied Water Science* 9, 1-12.
- Villela, S. M., Mattos, A., 1975. *Hidrologia aplicada*. McGRAWHill do Brasil, São Paulo.