Journal of Geographic Information System, 2016, 8, 238-247
Published Online April 2016 in SciRes. http://www.scirp.org/journal/jgis
http://dx.doi.org/10.4236/jgis.2016.82021

Morphometric Characterization of a Watershed through SRTM Data and Geoprocessing Technique

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Received 10 February 2016; accepted 23 April 2016; published 26 April 2016

Abstract

The aim of this study is to characterize the morphometry of a watershed using radar data Shuttle Radar Topographic Mission (SRTM) and GIS techniques. The study is conducted in the watershed of the Indaiá stream, which is located in the southwestern region of the municipality of Aquidauana, MS, Brazil and has an area of 94.6764 km². A tributary of the Taboco River consequently enters the Pantanal lowlands. Classical morphometric parameters were calculated and specialized through spatial analysis in geographic information systems. The main results of the morphometric characterization were the variables of form factor, drainage density, coefficient of compactness, and maintenance coefficient, as well as the relief parameters found, including the hypsometry, slope, aspect and relief dissection (horizontal and vertical amplitude). The integrated analysis of the variables (morphometric and relief) concludes that the watershed has low susceptibility to flooding but that the morphology of the relief and lithological structure favors the development of erosion processes in the watershed.

Keywords

SRTM DEM, Morphometric Analysis, GIS, Remote Sensing, Pantanal

1. Introduction

Morphometric analysis is a set of procedures that characterize the geometric and compositional aspects of environmental systems, serving as indicators of the related form, structural arrangement and interaction between aspects and the network of fluvial channels in a watershed in situations and values that exacerbate hydrological and geomorphological issues [1]-[13].

How to cite this paper: da Cunha, E.R. and Bacani, V.M. (2016) Morphometric Characterization of a Watershed through SRTM Data and Geoprocessing Technique. *Journal of Geographic Information System*, **8**, 238-247.
http://dx.doi.org/10.4236/jgis.2016.82021

Studies related to fluvial drainage have always played a central role in hydrological studies seeking to understand the occurrence, distribution, and movement of water and its properties. In geomorphological studies, they constitute one of the most active morphogenetic processes in the composition of terrestrial landscapes. According to Reference [7], the work developed by Robert E. Horton serves as the basis for numerous other research [2] [5] [14] [15], which have ranged from the establishment of laws on the development of rivers and their watershed in a quantitative approach to describing their morphometric character.

More recently, researchers have conducted morphometric analyses using remote sensing and geoprocessing techniques to characterize watersheds [16]-[28]. Previously, this type of analysis for computing the potential of obtaining environmental information demanded costly and time-intensive surveys, field surveys, and office space.

Since the Shuttle Radar Topographic Mission (SRTM) data on South America were first made available in mid-2003, there has been a great expectation with respect to the gains in knowledge concerning our territory, which has justified by the general lack of topographic data at appropriate scales.

Within this perspective, the TOPODATA project was developed at the Instituto Nacional de Pesquisas Espaciais (INPE) to build a national database of topographic data by providing a Digital Elevation (DEM) for all national territory and the major associated topographic variables (altitude, slope, aspects, profile curvature of the sides, horizontal curvature design of drainage channels and watersheds and catchment area). This project uses kriging methods to transform the original SRTM DEM with a new and improved 90 m to ~30 m resolution [29] [30].

The use of DEM through geographic information systems (GIS) has proven to be a powerful tool because it allows methods for analyzing topographic characteristics with quality and operational advantages. The SRTM data associated with geoprocessing techniques are presented as a way to obtain fast, accurate and low-cost calculations for use in morphometric analyses [28] [31]-[38].

The quantitative analysis of morphometric parameters is of immense utility in the development and prioritization of the conservation of soil and water at a watershed level [39]; within this perspective, the use of data obtained through remote sensing associated with GIS has proven to be a powerful tool for watershed analysis and management [26] [27] [40] [41].

However, the morphometric analysis approaches that are guided by geotechnology have focused on the characterization of specific parameters such as fluvial hierarchy, area and perimeter of the basin, compactness, and form [21] [42]-[44] while neglecting important variables such as the analysis of the degree of horizontal (H) and vertical (V) dissection (the introduced authors emphasize that SIG analyzes these articles and have found no H and V). Thus, there is a large gap in the literature that represents the integration of these variables.

In this context, this study aimed to characterize the morphometry of the watershed using both SRTM radar data and geoprocessing techniques.

2. Study Area Description

The watershed of the Indaiá stream is located in the southwestern region of Aquidauana municipality in the state of Mato Grosso do Sul, Brazil, between latitudes 20˚09'00"S and 20˚16'00"S and longitudes 55˚29'30"W and 55˚39'00"W, with an area of approximately 94.6764 km^2 (**Figure 1**). The Indaiá stream is a tributary of the Taboco River before it enters the Pantanal plain. According to Köppen, the climate belongs to the Aw sub-climate zone (tropical humid), with an average annual rainfall of 1.200 mm and maximum and minimum temperatures of 33˚C and 19˚C, respectively.

Geology and Geomorphology

Geologically, the study area comprises the Furnas Formation (Paraná Group), Aquidauna Formation and Alluvial River Current [45]. The sandstones that are predominant in the Furnas Formation are medium to rough, white to light yellow, and quite feldspathic. The highly micaceous sandstone layers are interspersed, often presenting cross-bedding and oligomitic basal conglomerations [46]. For reference [47], the sandstone group in Furnas comprises a sequence of alternating sandstone-shaped seats and plates that are yellowish to gray-white in color.

Reddish-brown brick stands in the sandstones of the Aquidauana Formation [45]. Mineralogically, the grosser levels are predominantly quartz grains, with rare, kaolinized feldspar [47]. For reference [48] red Aquidauana Formation sediments are the result of deposition in the continental environment (river, lake and floodplains).

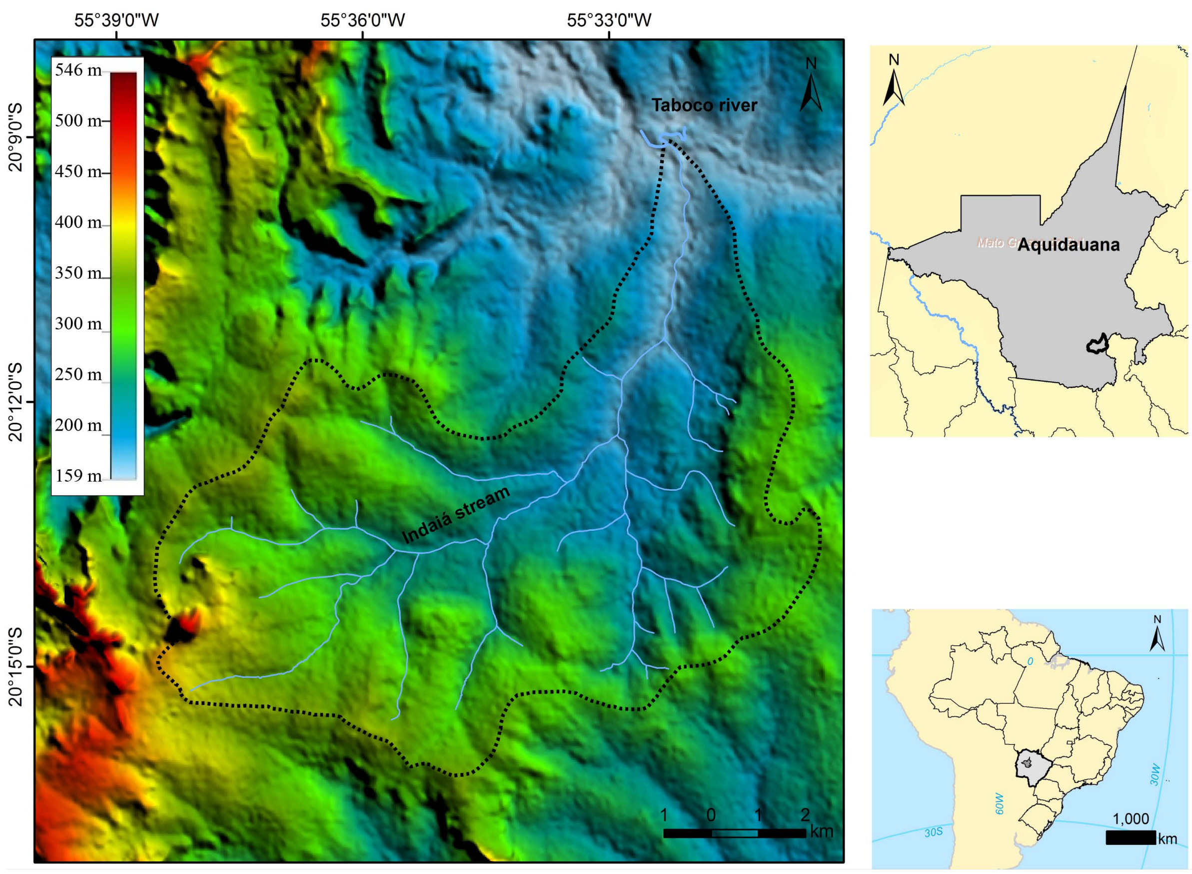

Figure 1. Digital model elevation (DEM) and location of the study area.

The alluvial deposits that are currently being deposited on the banks and beds of rivers and streams that drain the area are included. They are characterized by the presence of sand, silt, clay and gravel, usually at a lower level, and are overlapped by the sandy banks of the coarse-grained to fine, silt-containing levels [45].

As described by reference [49] the dominant relief forms are convex hills with slopes ranging from 6% to 20%, fluvial plain, hillocks and morrotes. The following units of relief and their respective forms (forms) were identified: river plain (APF), relief dissected into convex hills with slopes 6% - 20% (Vc), relief dissected into convex hillock tops (Tc), and relief dissected into convex hilltops (Tc).

3. Materials and Method

3.1. Data Used

The materials used were radar interferometric data from SRTM grid 20_57_ZN (GeoTIFF), mosaic optical images of high-resolution GeoEye satellite (ArcGIS 10® online) at a scale of 1:3.500 and a 0.63 m spatial resolution, and the computer applications ArcMap 10® and 13® Global Mapper.

3.2. Methodology

The methodology was based on the procedures described by Reference [1] [2] [5] [6] [50]-[53] according to **Figure 2**.

By analyzing the radar data SRTM (equidistant from contour extraction 15 m) together with the optical image resolution (GeoEye, spatial resolution of 0.63 m) that was extracted from ArcGIS 10 online, the basin and sub-basins were delimited, and the drainage network was extracted. The parameters of the basin, such as area, perimeter and length (main river, all channels and length of the basin), were generated automatically from the geometry tool, and other parameters were evaluated according to the equations described in **Table 1**.

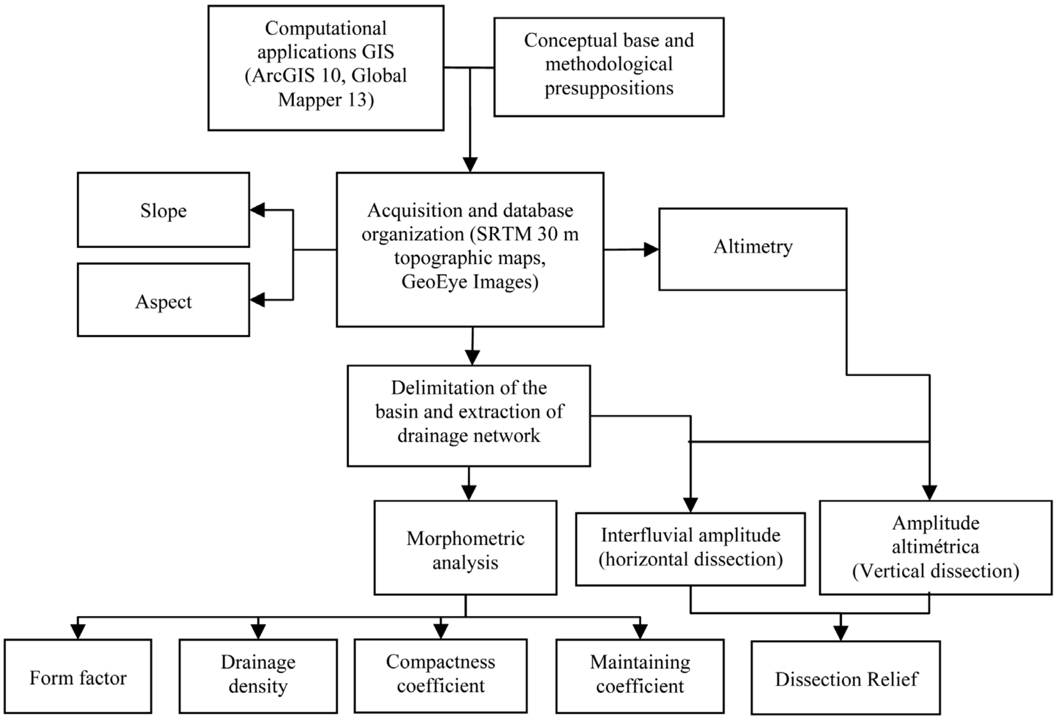

Figure 2. Methodological flowchart.

The numerical modeling of terrain was based on SRTM radar data, with the original resolution of 90 m refined by kriging to 30 m by reference [54]. A Regular Rectangular Grid Model (RRMG) was generated in accordance with previously described procedures [55]. The model was extracted by one-dimensional model relief. The hypsometric maps, clinography, aspect and interfluvial dimension were reproduced in the ArcGIS 10 environment. The steps taken were as follows: Arctoolbox > Spatial Analyst Tool > Surface.

4. Results and Discussion

Morphometric Analysis

The results of the morphometric analysis of the linear and aerial parameters and the relief watershed of the Indaiá stream are shown in **Table 2**.

Drainage area is one of the most important characteristics in hydrology. It reflects the volume of water that can be generated by rain water [27]. The Indaiá stream watershed has a drainage area of 94.6764 km^2, its perimeter is 49.0430 km^2, and it can be divided into seven sub-basins (**Figure 3(a)**). The development of the drainage system can be influenced in its morphogenetic activity by nature, geological structure, tectogenetic activities (endogenous) and morphoclimatic mechanisms (exogenous) [7] [38] [56].

The standard of the dendritic drainage basin is structured on the Paraná sedimentary basin characterized by outcrops of sandstones of the Furnas Formation and Aquidauana [45]. According to reference [7], this type of pattern is directly related to the uniform resistance of rocks and sedimentary structures.

The determination of order and the fluvial hierarchy is the first and most important step in the morphometric characterization of basin [39]. It is based on the criteria of reference [2] for determining the order of the channels and uses geoprocessing techniques to extract the basin drainage network, which was characterized as 4th order. In addition, 24 channels were characterized 1st order, 7 channels as 2nd order, and 2 channels as 3rd order (**Figure 3(a)**)

The watershed area of the Indaiá stream has a total length of 64.0938 km, including all of its channels, and the main channel is 17.9875 km (**Table 2**). Extensive channels are present throughout the basin. According to reference [38], the length of the channel is directly related to the topography; channels that are longer develop in smoother gradients, a fact that was evident in the study area, where the terrain features undulating soft forms

Table 1. Description of morphometric parameters (linear and areal relief).

Parameters	Formula	Description	References
		Linear parameter	
Hierarchical order (Strahler classification)	Fluvial hierarchy	Establishing the classification of a given body of water and the whole set of the watershed in which it is located.	[2]
Lr-Length of the main river	Higher-order channel		[1]
Lt-Total length of all channels (km)	Sum of all channels of the basin		[1]
		Areal parameter	
A-Drainage area (km^2)		Entire area drained by the set river system.	[7]
P-Perimeter (km)		Measure the two-dimensional contour of the basin	[7]
L-Basin length (km)		Distance measured in a straight line between the mouth and the highest point located along the perimeter.	[7]
Kc-Coefficient of compactness	$Kc = 0.28\frac{P}{\sqrt{A}}$	The compactness coefficient (Kc) associated with the basin form is a circle, and the relationship between the perimeter of the basin and the circumference of a circle of area is equal to that of the basin.	[1]
F-Basin form	$F = \frac{A}{L^2}$	Relating to the form shape of a rectangle, corresponding to the ratio between the average length and the axial length of the form.	[7]
D*d*-Drainage density ($km \cdot km^{-2}$)	$Dd = \frac{L_t}{A}$	The density of the drainage correlates the length of the flow channels with the watershed area.	[1]
Cm-Maintaining Coefficient	$Cm = \frac{1}{Dd} \cdot 1000$	This index is intended to provide the minimum area necessary for the maintenance of the one-meter flow channel.	[5]
		Relief parameter	
Altimetry amplitude (m)		Corresponds to the altimetric difference between the highest and lowest points along the basin.	[5]
Interfluvial dimension (Horizontal dissection)		Distance between channels.	[50]
Amplitude altimetry (Vertical dissection)		Drainage deepening of intensity.	[60]
Altitude			
Slope		The slope is the angle of inclination of the local surface relative to the horizontal plane.	[51]
Aspect		The slope variation of direction	[51]

that are characterized by the predominance of convex hills with an average slope of 5.50%.

The drainage density factor is directly related to climate, lithology of the rocks, relief, infiltration capacity and vegetation cover [7] [16]. The study area is in the category of low drainage density (0.6769 km/km^2), suggesting that the basin has good permeability. This behavior is associated with the infiltration process, which is favored by the lithological constitution of the Furnas and Aquidauana formations, which in turn essentially comprise coarse-grained sandstones.

The compactness coefficient of the basin is 1.4112. When the coefficient unit (1) corresponds to a circular shape (representing a tendency to flood), the form factor (0.4538) is considered low. From the combined analysis of the values found, it is possible that the basin has a low susceptibility to flooding; however, a more elongated pattern facilitates the runoff of rain water, thereby favoring the development of erosion.

According to reference [5], the maintenance coefficient is one of the most important numerical values for characterizing the drainage system and is intended to provide the minimum area for the maintenance of a flow channel tube [7]. The value obtained is 1477.32 km^2/km. Evidently, the basin is low in water course.

Table 2. Indaiá stream watershed parameters assessed.

Parameters	Total
Parameter linear	
Fluvial hierarchical order (Strahler classification)	4ª
Lr-Length of the main river	17.9875
Lt-Total length of all channels (km)	64.0938
Parameter areal	
A-Drainage area (km^2)	94.6764
P-Perimeter (km)	49.0430
L-Basin length (km)	14.4440
D*d*-Drainage density (km·km^{-2})	0.6769
Kc-Coefficient of compactness	1.4112
F-Basin form	0.4538
Cm-Maintaining Coefficient (km^2/km)	1477.3230
Relief Parameter	
Altimetry amplitude	387
Interfluvial dimension mean (m)	454
Altitude mean (m)	275
Slope mean (%)	5.50
Aspect (predominant direction)	North/East

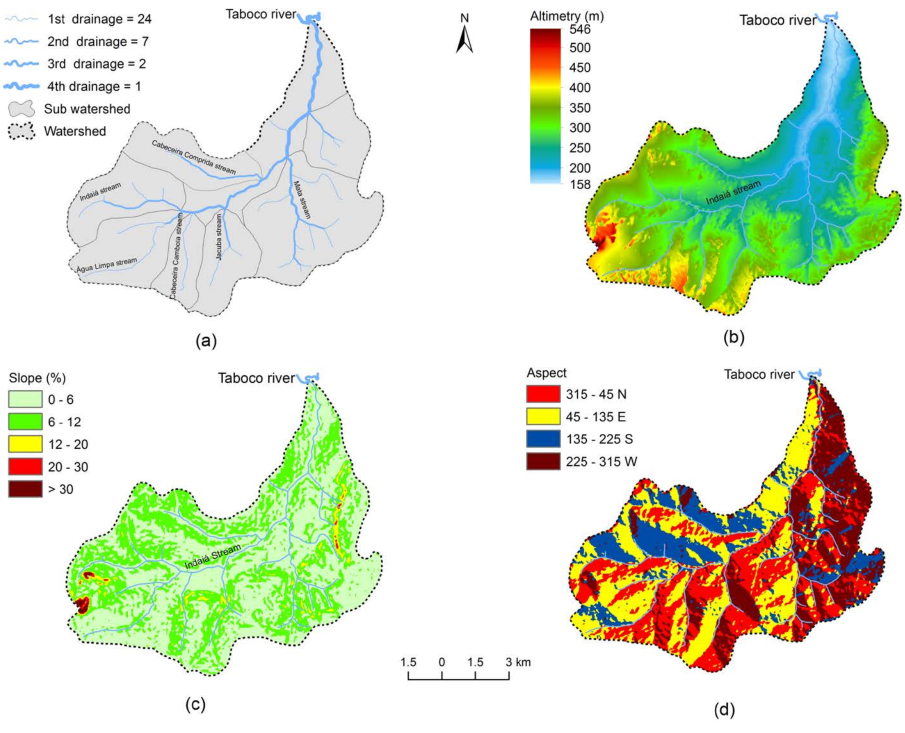

Figure 3. (a) Watershed limit, sub-basins and channel order, (b) altitude, (c) slope and (d) aspect.

The hypsometry was divided into 8 classes, ranging from an altitude of 546 m to 158 m (**Figure 3(b)**), setting an altimetry range of 387 m (**Table 2**). The altimetric amplitude from the mouth of the Taboco River to more than half of its middle course is very low (approximately 100 m). To the west is the highest altitude (546 m), which is associated with strongly undulation and has slopes exceeding 30%. In the east, towards the mouth of the Taboco River, the altimetric levels reach approximately 156 meters, where the relief ranges from plane (fluvial plain) to soft wavy (convex hills) that have slopes reaching <20%. The arrangement of the higher elevations to the west and lower east evidences the direction of flow of the drainage (O-L).

The mapping of the slope (**Figure 3(c)**) is an important analysis feature of a watershed. According to reference [57], the slope relates to the speed of the runoff, thereby affecting the time required for rain water to concentrate in the river beds that make up the network of the drainage basin. The flood peaks, infiltration and susceptibility to soil erosion depend on the speed with which the flow occurs on the ground of the basin.

In this sense, it is essential to understand the distribution of the relief slope because it provides information for the planning and mechanization of agriculture, the planning of engineering structures, and conservation practices [36] [37].

We identified that 61% of the basin dominates the lower slopes, with between 0% - 6% of the basin being associated with reliefs and exhibiting practically plane and soft wavy shapes; this area is located between the sources of its tributaries and the mouth of the Taboco River. The slopes steeper than 30% comprise 0.4% of the basin and occur in the west, in areas where the relief has strong waveforms that are characterized by the presence of hillocks and hills.

According to reference [58], the hillside "is the dominant element of relief in most regions, presenting itself as the most important form of relief for man, both for agriculture, as the other buildings work."

The mapping of the aspect (**Figure 3(d)**) of the Indaiá stream watershed presents a complexity in disposition that justifies the various flows into the basin; however, the aspects oriented to the north (N) and east (L) stand out.

To reference [59], the surfaces next to the Tropic of Capricorn tend to have aspects oriented north that are hotter and with drought compared with those in the south. In this sense, reference [60] stresses that any radiation flux that reaches a rather steep aspect positioned to the north in southern subtropical areas will be more intense than other aspects that have the same slope and location but are positioned to the south, a fact that favors the largest weathering of these aspects.

According to reference [60], the relief dissection of the drainage intensity is directly related to porosity, permeability and rock. The area watershed of the Indaiá stream is structured on the Furnas and Aquidauana Formations, which are composed of porous and friable sandstones [45]. This lithological characteristic favors the infiltration of rain water; consequently, the amount of water surface is lower, resulting in a number fewer channels and increasing distances between interfluves (**Figure 4(a)**).

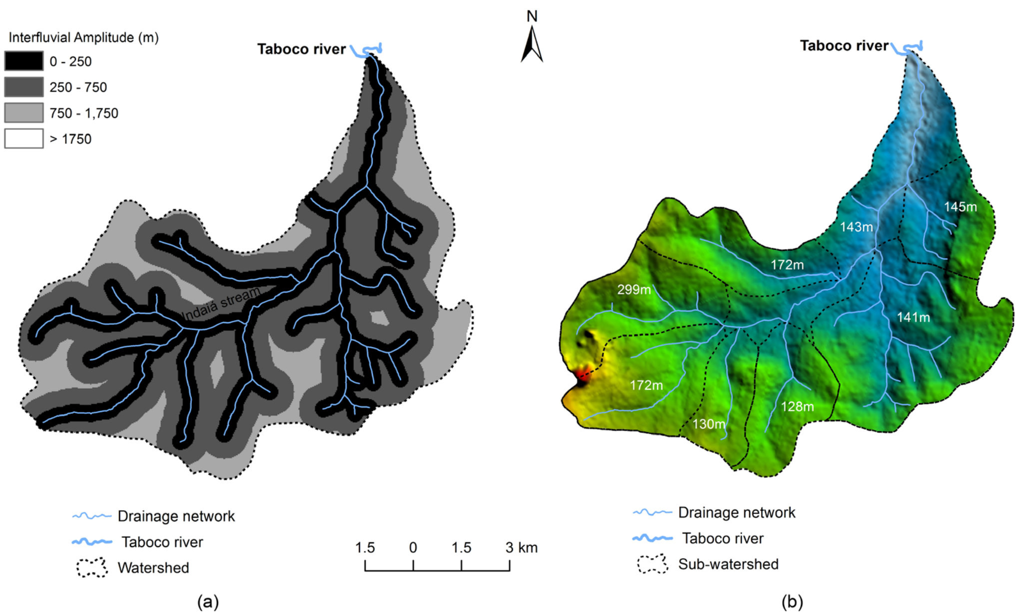

Figure 4. (a) Interfluvial amplitude (horizontal dissection), (b) vertical amplitude (vertical dissection).

By analyzing the horizontal and vertical dissection (**Figure 4(a)** & **Figure 4(b)**), we identified the predominance of channels at intervals of 250 - 750 m (average interfluvial size of 454 m). The notching of the very strong valleys (average 166 m) features a dissected relief that is dominated by hills with convex, U-shaped valleys.

5. Conclusions

The interferometric SRTM radar data showed satisfactory results in the morphometric characterization. This survey highlights the potential of radar metric products in the analysis of relief morphometry to serve as a basis for geomorphological mapping. Combined with other data (e.g., soil, use, vegetation cover, climate), such products can support diagnostics and environmental and land use analyses.

From the integrated analysis of morphometric variables, we conclude that the watershed has low susceptibility to flooding. However, the geological structure, which consists predominantly of sandstones and is marked by the presence of quartz associated with the hilly relief, favors the development of erosion by water.

The result of the morphometric characterization shows important variables, particularly in relation to the horizontal and vertical dissection cards that can assist in the planning, use and management of resources in a watershed that supports a rural settlement complex.

Acknowledgements

This work was supported by the Federal University Foundation of Mato Grosso do Sul (PROPP/UFMS). We thank the financial support provided by FUNDECT (PAPOS/2014).

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