Periódico Eletrônico
Fórum Ambiental da Alta Paulista
ISSN 1980-0827 – Volume 17, número 5, 2021

Applications in remote sensing and environmental analysis: Digital geomorphometric characterization of the relief in *Ribeirão das Cruzes* Watershed, Selvíria / MS (Brazil).

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ISSN 1980-0827 – Volume 17, número 5, 2021

SUMMARY

The present study aims to describe the morphologic and geographic structuring and report a relief morphometric analysis in a cutout of the environmental planning. To do so, geoprocessing techniques were widely used and supported by systemic theory. The main objective is to process relief data in Geographic Information System (GIS) and contribute to the database of characteristics from different local geomorphometric variables. Thus, the theorical basis of the research suggests the use of General System Theory based on their concepts to understand the morphologic structure of the relief at different levels, also the condition of the relief shapes and their classification. This case study occurs methodologically, defining the relief category as an environmental component of direct and vital interaction with other resources and dynamic components, considering mainly the whole environmental system. In this study, the environmental system is the *Sucuriú* River watershed. Therefore, to get the environmental analysis of the relief, the methodology consists of pre-processing and processing of digital land modeling data based on Synthetic Aperture Radar (SAR) records. Those can obtain different characteristics by using the methodology of geomorphometric variables extraction, which are the set of variables subject to land measuring. The results should cartographically reveal the dynamics and structural morphology of the relief, observing important parameters of relief configuration and concluding with the presentation and correlation of the relief shapes dynamics in all the considered environmental system.

KEYWORDS: Geoprocessing. Digital Elevation Model. Morphometry

1 INTRODUCTION

Studies and environmental analyzes (both general and complex ones) should integrate the characterization of different elements and natural geographic components. The relief interpretation is an important geographic component and an interesting indicator of dynamic processes in the environmental system. Brazil presents a huge variety of relief compartments, created by internal and external processes, and their shapes integrate a series of several parameters and geological and geomorphological formations that feature the national territory.

The purpose of this brief case study is to identify and analyze, based on survey and data extraction, the relief shapes, their parameters and their influence on the environmental dynamics of a watershed. The procedures performed can directly collaborate to measure the relief transformations in the environment and in the system (ROSS, 1991; TONELLO et al., 2006).

The performance of the environmental analysis using parameters obtained from the Digital Elevation Model (DEM) offers a picture of the geomorphological evolution and the changes and impacts that the use and exploitation of natural resources cause on the environmental system (ROBAINA et al., 2010; FERNÁNDEZ et al., 2012; TINÓS et al., 2014). The methodology consists of reading the relief model in the watershed cutout. The steps to carry out this study are based on the use of remote sensing and geoprocessing with Geographic Information System (GIS). Thus, it is taken into consideration the interaction of the geomorphometric characteristics of the area with other types of elements that compound a local landscape (FORNELOS; NEVES, 2007).

Morphometric data surveys and relief patterns collaborate with it by providing the basis for integrated management plans of areas that are economically and environmentally important. The data obtained can be used to suggest research and interventions that focus on

the rational use of resources and on the respect for the ecological processes of the selected natural area (MUÑOZ, 2009; OLIVEIRA et al, 2010).

The parameters used provide direct data related to certain processes of the surface dynamics of the terrain. Those processes reveal barely perceptible phenomena that are intrinsically linked to the shape and modeling of the relief, as well as the morpho-lithological formations of the area (NARDIN; ROBAINA, 2005; TRENTIN; SANTOS; ROBAINA, 2012).

The morphometric parameters identified and presented in this study are related to the hypsometric characteristics of the area, altimetric amplitude, slope rates, shaded relief and preferential slope orientation (VALERIANO, 2008; MUÑOZ; VALERIANO; WEILL, 2011). The extraction of each of the variables occurs with data treatment and processing techniques contained in the Digital Elevation Model (DEM) of the area. They can be performed by several specific tools for digital processing of the relief based on GIS (VALERIANO, 2003). For this study, a free and open-source software was used, more specifically, the QGIS 3.6 Noosa® version and some of its most important geoprocessing complements.

The main objective is to produce a survey of the local relief characteristics and collaborate with the enhancement of the geographic database concerning *Ribeirão das Cruzes* Watershed, in Selvíria / MS (Brazil). With that, some basis can be provided for future and correlated studies that analyze other variables of the system.

Finally, in addition to the arrangement and orientation of the relief, the characterization of the shape points to the basic conformation of the landscape structure, besides other elements. It is also pointed the influence on the environmental system and on the organization of social and economic activities in both urban and rural space. Therefore, understanding the morphological and morphometric structure of the relief may reveal characteristics inherent to the landscape and in all its evolutionary dynamics.

2 OBJECTIVES

The main objective of this study is related to the acquisition of information with conceptual structures and practices of environmental analysis. The study also focuses on the extraction of parameters on digital geomorphometric models of *Ribeirão das Cruzes* Watershed (Selvíria/MS).

It was intended to apply some practical geoprocessing techniques with the Geographic Information System (GIS). Hence, the complementary objectives are the basis and the consequence of these surveys, highlighting the importance of public data on the environment.

One of those objectives is about the production and complementation of information for a primary geographic database of the municipality. That information supports the analysis in other watersheds from the region.

This work was developed in order to indicate spatial information that can be managed and processed by resources at a GIS. That also involves acquisition tools (sensors) of data and forms of qualitative and quantitative representation of the target variables.

3 METHODOLOGY

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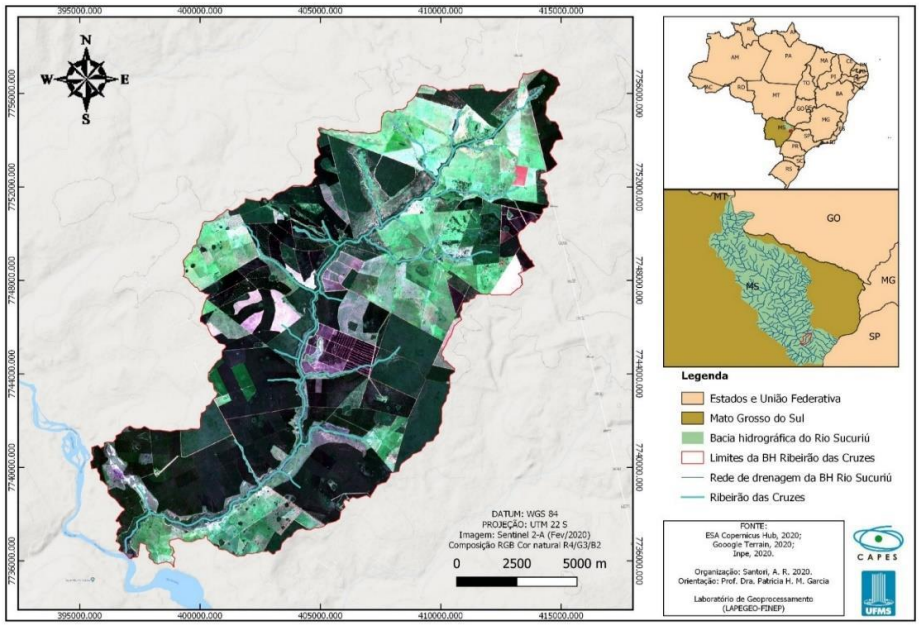
The area selected for this case study and for the application of acquisition techniques of relief data was *Ribeirão das Cruzes* Watershed, an area of approximately 212 km², located between coordinates 20° 15’ 36” S; 20° 30’ 33” S and 52° 05' 05" W; 51° 45’ 58” W, altitude range between 275 and 455 meters and average of 365 meters. This is a third-order magnitude stream, and it is a direct affluent of *Sucuriú* River’s left bank.

In Figure 1, the watershed can be seen from its location context in the eastern region of the state of *Mato Grosso do Sul* (Brazil). Likewise, it is possible to see the watershed’s position regarding the subsystem, which is the hydrographic unit with the highest hierarchy (*Sucuriú* River Watershed).

Figure 1: Location of the study area (*Sucuriú* River Watershed)



Source: AUTHORS, 2020.

The main tool used for this methodology is the reproduction of techniques and process for the treatment and extraction of environmental data, having as its main support the use of elements from Geotechnologies. In this study, it was essential to use the Remote Sensing basis via active sensors with the Raster database acquired from sub-orbital imaging by Synthetic Aperture Radar (SAR).

The intrinsic relationship between altimetric components and other components of the environmental system can be exemplified by surface and subsurface processes. Thus, these parameters are the basis for several correlations between other factor and variables from nature (MUÑOZ, 2009).

All products targeted in this study consist of relief modeling characteristics, and they can be extracted from files based on Raster images known as Digital Elevation Models (DEM). The accuracy of the SRTM (Shuttle Radar Topography Mission) data has already been reaffirmed by several studies about plenty of environmental contexts of application (VALERIANO, 2004; FORNELOS; NEVES, 2007; VALERIANO, 2008; MUÑOZ; VALERIANO; WEILL, 2011; OLIVEIRA et al., 2010; ROBAINA et al., 2010; ROBAINA et al., 2010; FERNÁNDEZ et al., 2012).

DEM data are generally available in file format that can be open and worked on in different geoprocessing environments. DEM consist of a digital reproduction of the terrain modeling in its different forms, integrating numerical information on the relief in meters and topographical data at certain scales (VALERIANO, 2003; VALERIANO, 2008).

The execution of these techniques was based on the wide use of resources and algorithms available on Geographic Information Systems (GIS). In this specific case, we chose to use the free software QGIS 3.6 Noosa ®.

The methodology uses geoprocessing techniques to handle the relief information in the DEM raster file. The grid was obtained from the TOPODATA/INPE database called "20S535ZN", which covers the entire watershed in study.

The pre-processing steps followed the methodology presented by Sobrinho et al (2010), and the following procedures were carried out: the raster corrections, the cutout, the reprojection of coordinates. Also, there was the application of algorithms related to delimitation and extraction of the network regarding drainage and boundaries from the watershed. To obtain certain variables, specific tools for land analysis were applied to the matrix data.

3.1 HYPSOMETRY

It consists of altimetry data with the definition of the terrain height regarding the sea level. This technique is commonly used to obtain the graphical representation of the terrain altitude. Therefore, hypsometry corresponds to the definition of classes or values of altitude in a determined horizontal unit in space, and this phenomenon is represented by altimetric dimensions (VALERIANO, 2003).

Dimensions vary within a range defined by the surface model. The altimetric amplitude is one of the main data provided by DEM, and the minimum, average, and maximum terrain altitude information (altimetric range) are correspondent to it. The analysis can be done by simply changing the Raster configuration, assigning a new symbology at the GIS. After that, it is possible to classify the class intervals and assign them color gradients for visual interpretation of the data.

3.2 SLOPE

The slope classes compose a gradient on which the reasons for the altimetric variation or the variation of the elevation are based on. The slope values allow the analysis of the relief undulation, and from the analysis of the slopes, it is possible to identify the inclinations of the watershed slopes (RECKZIEGEL; ROBAINA, 2006).

To extract the slope data from the area, it is necessary to use the analysis tool of the Raster data called "Slope", which can be done by GDAL algorithm (2.4.1 version). One of the most important points for this variable is the chance to identify large and abrupt variations along the terrain. Considering that, it is also important to select a set of colors that suit better the representation of the slope percentages in the area.

After extracting the data, it was decided to vectorize the information obtained in order to extract other quantitative data on the occupation of slopes. The same procedure was performed regarding the hypsometric chart.

3.3 SHADED RELIEF

The shaded image of the relief represents the mapping of the DEM dimension values applied in gray level. This parameter indicates the lighting conditions or direction of the relief illuminants from the digital model. The shaded relief variable consists of shaded models of three-dimensional superimposition of topographies and terrain roughness (HORN, 1981).

The composition of the relief shading can be performed by using the "Shading" tool on the Raster analysis complement of the terrain. For the extraction of the shaded relief, it is necessary to indicate the horizontal (azimuth) and vertical angle values. In this study, we chose the direction of 50º, which also corresponds to the lighting angle (CONCEIÇÃO; SILVA, 2013; TINÓS et al., 2016).

3.4 SLOPE ORIENTATIONS

The orientation of the terrain slope is an important variable related to terrain lighting (VALERIANO, 2003). The geometric relationship of surface exposure of slopes and terrain can be indicated as a steering compartment. That is because the representation of the relief structure assumes its orientation in some geographic direction in octants.

The slope orientation (also called exposure or direction) is defined as the azimuthal angle corresponding to the greatest slope of the terrain in downward direction, and it is expressed in degrees, from 0_o to 360_o (OLIVEIRA, 1984).

To produce this variable contained in DEM, the GIS needs a tool to analyze and calculate the slopes of the terrain, indicating the downward slope of the relief with geometric schemes. In order to extract the data with the GIS, it was necessary to access the terrain raster analysis complement via the "Aspect" tool or the "Slope.Aspect" tool at the GRASS GIS algorithm (7.6.1 version).

4 RESULTS

The results obtained consists of data and information previously related by the analysis of some morphometric parameters of the relief. For that, it was used the Digital Elevation Model (DEM) of *Ribeirão das Cruzes* Watershed (Selvíria/MS).

The parameters obtained are reflected in the calculation of local relief derivations, such as hypsometry, slope, slope orientation and other parameters. Each parameter was established according to the exploration of the step sequence and the conceptual basis presented in the methodology.

The first relief data obtained as a result were both the altimetric dimensions and the altimetric amplitude values. The data could be measured by the construction of the hypsometric chart. To organize the table that presents the area quantification, the range of classes determined was 20 meters.

Table 1 presents details of the altimetry or hypsometry parameters of *Ribeirão das Cruzes* Watershed, relating its main characteristics, the occupation in area (km^2) and in percentage (%).

Table 1: Altimetric dimensions of the Digital Elevation Model and local characteristics.

Classes (20m)	Relief characteristics	Area (km2)	%
275-294	Predominantly flat areas close to the main channel and floodplain areas (Fluvial Plain).	2.618,5	1
295-314	Predominantly flat areas close to the main channel and floodplain areas (Fluvial Plain).	16.398,7	8
315-334	Predominantly flat areas close to the main channel and floodplain areas (Fluvial Plain).	23.300,1	11
335-354	Predominantly flat areas close to the main channel and floodplain areas (Fluvial Plain).	37.930,3	18
355-374	Areas of more undulating relief surrounding the smaller river sources along the channel.	47.023,8	22
375-394	Areas of more undulating relief surrounding the smaller river sources along the channel.	44.296,8	21
395-414	Areas of more undulating relief surrounding the smaller river sources along the channel.	27.780,6	13
415-434	Higher and dissected areas in watershed bands and hilltops	10.979,7	5
435-455	Higher and dissected areas in watershed bands and hilltops	1.705,8	1
Total		**212,3**	**100**

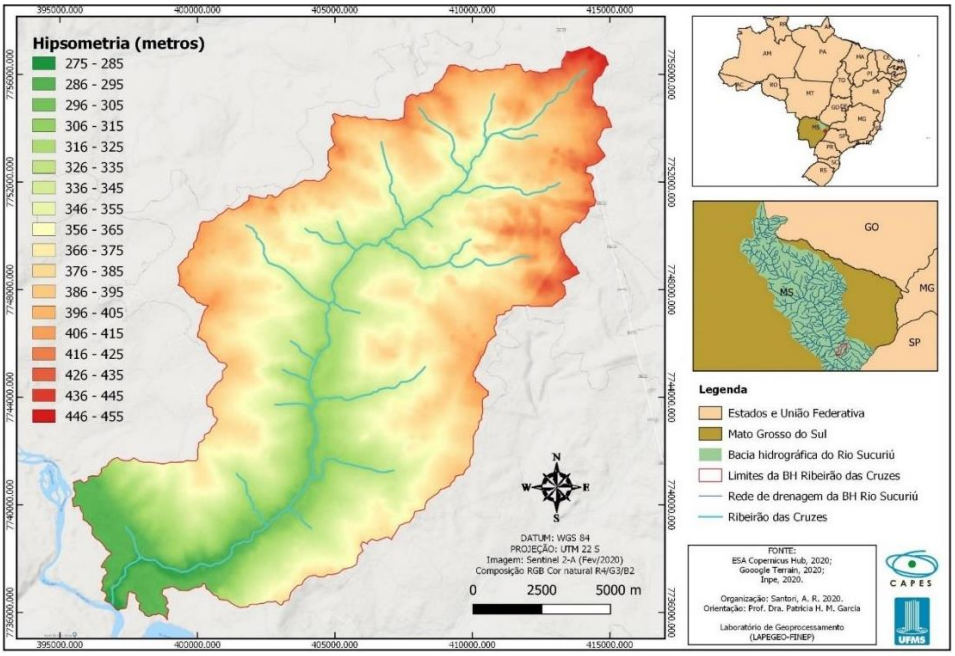
Source: AUTHORS, 2021.

The height of the cutout made in the DEM for *Ribeirão das Cruzes* watershed varies its amplitude between 275m and 455m. The largest portion of the area is conditioned between altitude ranges of 335 to 394 meters (61% of the watershed). The hypsometric map can be considered relief data in form of altitude images of the area.

The highest altitudes were recorded in the northern and northeastern regions of the watershed, with values ranging from 415 to 455 meters (6% of the watershed). The lowered areas were distributed preferentially close to *Ribeirão das Cruzes*'s main riverbed and in the southern region of the watershed, concentrating in values between 275 and 315 meters (9% of the watershed). The most frequent elevations in the local relief are those corresponding to the range from 355 to 374 meters (22% of the watershed), spread over wide areas of medium slopes and lowered tops.

In the representation of the hypsometric chart, larger intervals of 10 meters were defined in each class in order to produce greater and more striking detailing of the altimetric variation. The result obtained can be seen in the information and characteristics of the hypsometric chart (Figure 2).

Figure 2: Hypsometric map of the *Ribeirão das Cruzes* Watershed.



Source: AUTHORS, 2021.

Observing the slope variable (element that represents the aspect of roughness in the area relief), the set of classes obtained as results follow the structure, criteria and definitions of relief characteristics adopted by Brazilian Agricultural Research Corporation (EMBRAPA, 1999). Four of those mentioned areas were identified in the study area.

The first class was the second with the highest occupancy in the watershed, corresponding to values from 0 to 3%. This class occupy considerable swaths of the site, representing about 33% of the total area. The Smooth-Wavy class with values of 4-8% was predominant, distributed throughout the area and its occupation was equivalent to 63% of the area. In the region, most pedological formations correspond to red oxisols (LVe/LVd), a tendency in flat environments.

Certain ranges can also be found with slopes based on the Wavy class of 8-20%. The tendency presented was a very visible association of natural or anthropogenic cuts in the relief pattern, a situation that may be associated with different factors. However, this class presented about 4% of the watershed area and was basically concentrated in small areas in the high course. Finally, the presence of slopes greater than 20% was found, but representing a tiny 0.1% of the total.

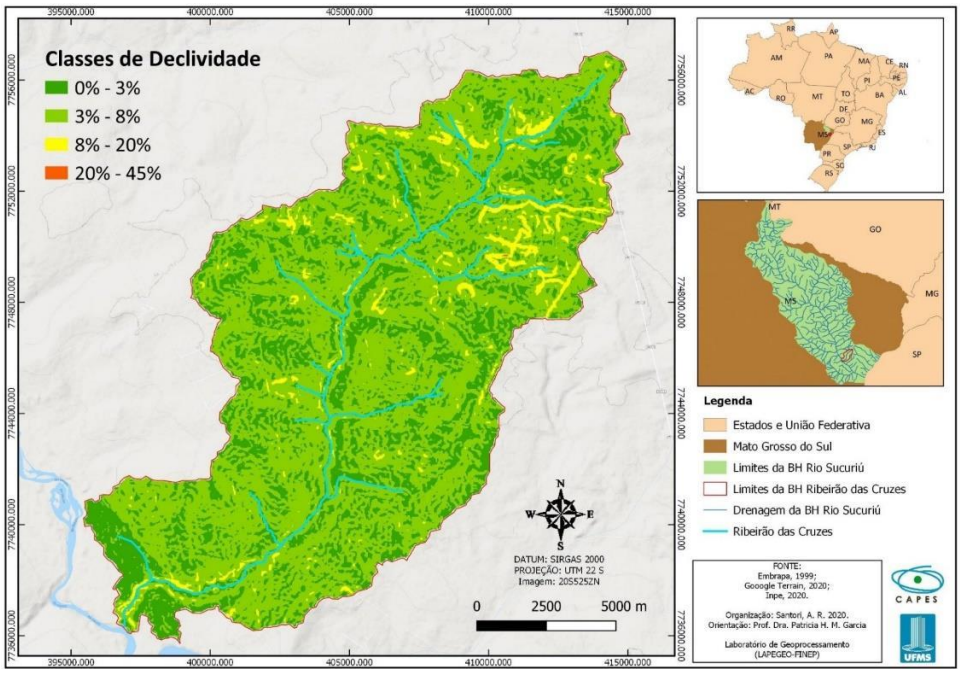
In the slope variable, the areas with higher altitude are more restricted to the watershed's drainage headwaters. Parallel to it, more wavy slope percentages (<20%) are presented in strips that seem to obey steeper areas of the regular stream bed and terrain areas that have suffered some sort of indirect influence.

The linear pattern presented by slopes greater than 8% may be associated with indirect irregularities caused by the shading of the terrain with the canopy of arboreal vegetation (reforestation). Thus, it does not represent something related to the evolution of the relief, but wrong readings of the sensor related to interferences from targets of the terrain.

When interpreting the map, it was found that the steepest areas are concentrated mainly in the upper course of the watershed, and the slopes of 0% to 3% and 3% to 8% extend over a large part of the area. Hence, it is presented the existence of a predominantly flat relief

to a very slightly undulating relief. In Figure 3, it is possible to observe the pattern and spatial distribution of the four classes of slopes.

Figure 3: Slope map of *Ribeirão das Cruzes* Watershed.



Source: AUTHORS, 2021.

The next variable consists of the shading effects caused by the illuminants and reproduced by the shaded relief maps. The illuminants that presented the best view condition for relief shading were in the west, south and southeast directions.

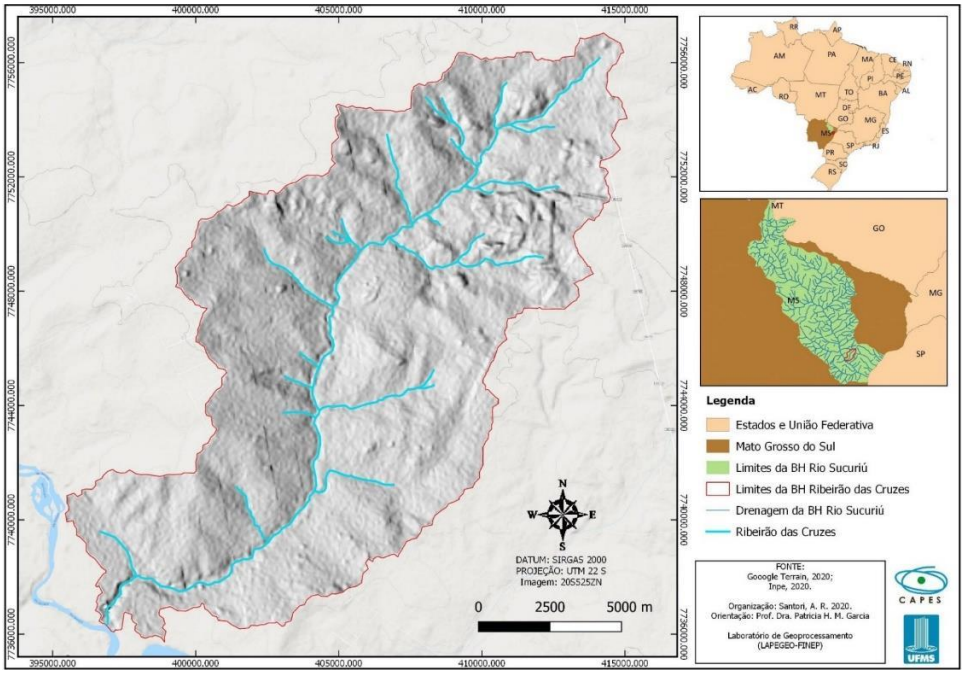
The results obtained from the position value and the light source of the shaded relief (at 50°) proved to be correct and aligned with the tendency of low variation and structural complexity found at the DEM of the study area. The low roughness of the watershed implies directly in the variable of drainage density. That is becuase little roughness of the terrain implies less notched flows.

Considering the watershed cutout, the greatest predominance of shading was in the areas close to the watercourse and in the upper course. In contrast, there is a flat tendency which happens without any form of dissection (more accidental) of the terrain. That tendency is verified again in areas of the lower course and in areas close to the interfluve with the *Sucuriú* River.

Approximately 80% of the watershed has a largely smoothed relief, and the lowered areas are in line with the drainage or in scars distributed in lands with intensive use of the soil.

Observing Figure 4, we can identify parts of the morphometric characteristics of the relief in the area. The roughest sectors or those with a greater indication of depth can be associated with slopes greater than 10% and 20%.

Figure 4: Shaded relief map of *Ribeirão das Cruzes* Watershed.



Source: AUTHORS, 2021.

The orientation of the slopes collaborates with the analysis of the profile and direction that the relief modeling can produce under certain climatic, geological and geomorphological conditions. The metric for exposure of the slope to lesser or greater contact with solar radiation was generated based on the altitude grid. Plus, the values are expressed in degrees.

Regarding the different orientations, in general, there were good distribution and balance across the study area. Areas with slopes oriented in all directions were found, but preferentially to the west and south of the watershed. This factor may indicate a slight inclination of the watershed to the tributary direction towards *Sucuriú* River. The orientation areas are described quantitatively below to contribute to the spatial analysis. They also indicate the north and northeast directions as less preferable regarding the slope of the relief.

Table 2 was created to organize and present the slope tendency of exposure and direction in the place, indicating the data in area (km² and %) for each type of orientation (0°, 45°, 90°, 135°, 180°, 225°, 270°, 315° and 360°).

Table 2: Position and orientation of slopes and corresponding areas.

Orientation	Area (km²)	%
Flat	246,7	0,1
North	21.501,8	10
Northeast	18.729,7	9
Northwest	28.181,7	13
East	20.987,7	10
West	31.909,8	15
South	31.796,8	15
Southeast	28.803,3	13,9
Southwest	30.175,1	14
Total	**212,3**	**100**

Source: AUTHORS, 2021.

FINAL CONSIDERATIONS

The elements and parameters analyzed contributed effectively to the characterization of the morphology and local structuring of the relief, providing morphometric data for the composition of the area's geographic database. Three maps were produced for the visual representation of some part of the variables obtained, and the others were described quantitatively based on certain calculations.

In general, the results obtained in the set of selected variables brought direct answers about the condition of the terrain in the study area. Plus, each data obtained could be observed and validated later with the field trip.

The altimetry showed a variation of 180m between the minimum and maximum values, and the average altitude was 365m. The slope and shaded relief showed a flat to predominantly flat relief with predominance of hills with concave and flat tops. The greatest roughness of the terrain (above 8%) are concentrated in an area of the micro-basin with lines in a pattern that seems to be produced by interference from canopies.

The results were closed with the quantitative data of the last two morphometric variables obtained. Thus, the relief orientation was well distributed along *Ribeirão da Cruz* watershed, with a slight predominance of areas oriented to the west, south and southwest octants. The data represented weak dissection power of the relief and little fluvial activity of the low-order stream in the area, determining once again the latent flat condition of this sedimentary region.

Correlating all the morphometric parameters obtained in the Digital Elevation Model, we can observe that *Ribeirão das Cruzes* Watershed is totally constituted by relief patterns with characteristic of areas of sedimentary deposition and fluvial plains.

Finally, the strong presence of convex tops from low to very low dissection stands out, complemented by the low roughness of the relief indicated by the shading and the stream low density. Therefore, the position of the watershed is conditioned to the influence of the alluvial

plain of the subsystem (*Sucuriú* River). Plus, the river activity is low, still restricting the flow and the dissection degree of the watershed.

ACKNOWLEDGEMENTS

We thank *Coordination for the Improvement of Higher Education Personnel* (CAPES) for the financial support, the Geoprocessing Laboratory (LAPEGEO/UFMS) for the collaboration, and the Postgraduate Program in Geography (PPGGEO) at the Federal University of Mato Grosso do Sul, Campus of Três Lagoas/MS (CPTL/UFMS).

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