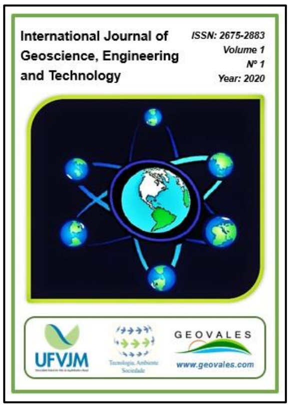
International Journal of Geoscience, Engineering and Technology
ISSN: 2675-2883
https://doi.org/10.70597/ijget.v1i1.361
Volume 1 – Nº 1 – Year: 2020 – pp.1–6
www.geovales.com



Received:
March 30, 2020

Accepted:
April 24, 2020

Published:
April 30, 2020

Morphometric characterization of the Todos os Santos river basin in Minas Gerais – Brazil

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Abstract

This study aimed to morphometric characterization of the watershed of the Todos os Santos River (TSR), located in the northeast of Minas Gerais in Brazil. The Todos os Santos River is one of the most important tributaries of the Mucuri River in the Mucuri Valley. Based on the digital elevation model, known as SRTM (Shuttle Radar Topography Mission) the data were processed in open software to obtain the slope, elevations, and aspect values, in addition to delineate the watershed and extracting the streams, which presented through maps, tables and graphs. Furthermore, the whole proceed data were reclassified in a new data range (called classes) according to different criteria for each data type. The TSR basin has an altimetric amplitude of 830m. The biggest elevation area is class 3 (range: 300 to 400m) with 604.78 km², representing 27.53% of the total area of the watershed. The most predominant slope is undulating relief, corresponding 49.67% (1091 km²) of the TSR watershed total area. About the aspects (slope orientation), there is a trend direction to NE-SW but, the distribution of the aspect classes throughout the river basin shows a balance in the distribution of the slope directions. The results also indicated that the headwaters of the TSR have a higher slope variation after this point, and the river shows uniformity behavior. The results accomplished may serve as a guide for other works in the TSR watershed and similar regions.

Keywords: Hydrographic basin, Topography, Relief, Todos os Santos river.

1. Introduction

The morphometric characterization based on surveys of remote sensing and its correlations can be presented as essential for the development of studies and research of geological, environmental, topographic, hydrological, urban and rural cities, geographic development, among others.

The characteristics and conditions of a basin or drainage basin determine the development of the landforms within it. Therefore, identification of the most important characteristics of a basin is integral to understanding its geomorphology (Patel et al., 2012; Arabameri et al., 2020).

The morphometric behavior depends on its physical characteristics such as relief, soil types, area, drainage network and vegetation. The present work is focused on the characteristics of the relief as the slopes, the elevations, the orientations of the slopes, as well, the delimitation of the hydrographic basin of Todos os Santos River based on topographic data. The basin is located in the northeast of the state of Minas Gerais in Brazil (Figure 1).

The characteristics of the relief directly influence the river courses. In this sense, the data processed can serve as a basis for future studies and research related to the region.

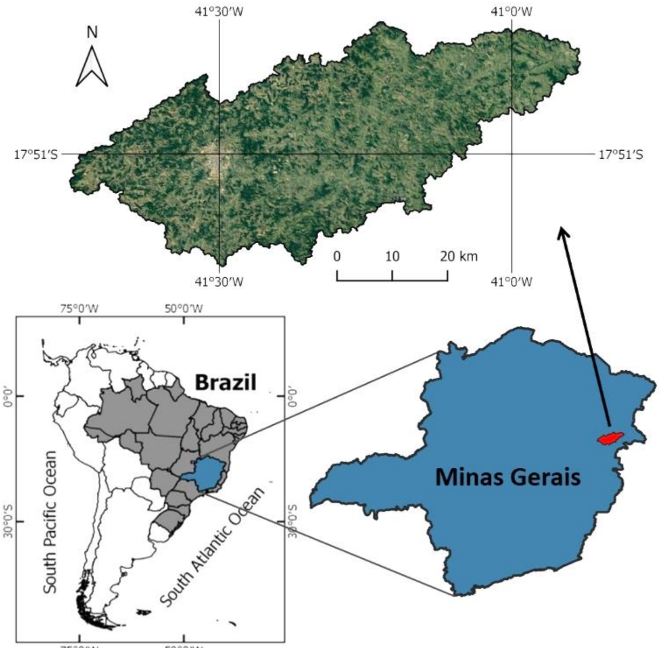

Figure 1 – Location of the study area in the state of Minas Gerais in Brazil.

2. Methodology

The methodology used for the morphometric characterization is based on works present in national (e.g. Cassettari & Queiroz, 2019; Gomes, 2017; Cunha & Bacani, 2016; Gomes & Gomes, 2015; Florenzano, 2008) and international literature (e.g. Anbazhagan et al., 2011; Fryirs & Brierley, 2013; Deng, 2007; Leopold et al., 1992). Also, open elevation data was adopted as a data source for morphometric analysis.

The use of numerical data (numerical elevation models) requires the use of geoprocessing software. The proposed study will use the free software QGIS (version 3.2.3) integrated with the analysis tools of others free software GRASS (version 7.4.1) and SAGA GIS (version 2.3.2), which includes a set of tools for building hydrological analysis based on the digital elevation model.

The numerical database of the study region was obtained by the National Aeronautics and Space Administration (NASA), during the mission known as SRTM (Shuttle Radar Topography Mission).

The digital elevation model (DEM) of the SRTM, with 1 second of arc (approximately 30 meters of spatial resolution) is distributed free of charge by the American government through the Earth Explorer website of the American Geological Service - USGS. In the present study will be used three sheets: s18w042_v3, s18w041_v3, and s19w042_v3.

To use the SRTM data, it is necessary to carry out two initial procedures for data processing, first converting the global coordinate system to local, that is, the WGS84 is reproject to UTM and the second is the elimination of sinks (depressions/holes) in the DEM.

The procedure for eliminating sinks is applied to digital elevation models to remove imperfections in these data. These imperfections, characterized as depressions or peaks must be corrected to generate flow networks and delineating drainage basins more faithfully to the terrestrial truth (Hengl et al., 2004; Göbel, 2012). The depression filling algorithm proposed by Jenson & Domingue (1988) is the method most commonly used in GIS (Wang & Liu, 2006).

The next stage aims to obtain the flow direction from each cell in the MDE grid. The direction of flow is necessary in hydrological studies to determine the paths of water, sediments, and movement of contaminants, being useful also in the delimitation of the contribution area of the watercourse (Tarboton, 1997).

The drainage network of a DEM is the group of cells where the accumulated area exceeds a certain value, and theoretically coincides with the location of the natural channels in a real terrain. The drainage network is obtained with the prior information of the area accumulated in this work adopted the threshold value 5 for a denser channels network.

For the analysis of the morphometric characterization and delimitation of the watershed of the Todos os Santos River (TSR), variables were extracted from the elevation model (SRTM), such as slope, direction of slopes, and the drainage network for TSR. The next step was to reclassify the processed data based on tables (1 to 3), for the generation of thematic maps and statistical analysis. The declivity data were divided into six new classes according to the classification proposed by Embrapa (1979). According to this proposal, the classes are distributed in 0 - 3% (flat or almost flat), 3 - 8% (gently-undulating), 8 - 20% (undulating), 20 - 45% (heavily-undulating), 45 - 75% (hilly) and greater than 75% (Steep). The names of each class were adapted to meet (in general) the landscape unit classifications of Van Zuidam and van Zuidam-Cancelado (1979), Van Zuidam (1983), and also to a new proposed classification of Listyani (2019).

The altimetric data was reclassified for the six classes (Table 1), as well as pseudocolors were assigned to each class, in order to facilitate their interpretation and visualization.

The aspect identifies the downslope direction (the horizontal orientation of a surface and it was calculated in degrees). Each facet of the surface was assigned a code value (class) each represents the cardinal or ordinal direction of its slope. The respective directions were reclassified into nine classes: north (N), northeast (NE), east (E), southeast (SE), south (S), southwest (SW), west (W), northwest (NW) and north (N) shown in table (3).

In this study, the classification presented by Strahler (1952 and 1957) for the stream (drainage) network order was adopted.

Table 1 – Range of the elevation classes adopted for the reclassification of SRTM data in the TSR watershed.

Classes	Elevation (m)
1	< 200
2	200 – 300
3	300 – 400
4	400 –500
5	500 – 600
6	600 – 700
7	700 – 800
8	800 – 900
9	> 900

Table 2 – Slope classes according to the Embrapa criteria.

Classes	Slope (Relief) (Embrapa, 1979)
1	Flat or almost flat (0 – 3%)
2	Gently-Undulating (3 – 8%)
3	Undulating (8 – 20%)
4	Heavily-Undulating (20 – 45%)
5	Hilly (45 – 75%)
6	Steep (Mountainous) (> 75%)

Table 3 – Aspect classes used to reclassify the data.

Classes	Aspect Slope angle (degree)	Direction
1	0 – 22.5	N
2	22.5 – 67.5	NE
3	67.5 – 112.5	E
4	112.5 – 157.5	SE
5	157.5 – 202.5	S
6	202.5 – 247.5	SW
7	247.5 – 292.5	W
8	292.5 – 337.5	NW
9	337.5 – 360	N

3. Results and discussion

The results of the morphometric analysis of based on SRTM data processing of the TSR basin are shown in tables (4 to 6). The watershed covers an area of 2196.53 km ². All data were reclassified for the purposes of statistical analysis and an area count (in km²) was performed for each class. As a final procedure, hypsometric (elevations) and slopes maps were prepared for the watershed of the Todos os Santos River, as shown in figures (5A and 5B). The aspect and drainage (channels) networks are illustrated in figures (5C and 5D).

The table (4) shows the six classes of elevations. The class 9 is the smallest area as a percentage of the total area of the TSR watershed with a value of 0.12%. It's also represents the highest regions of the watershed reaching up to 993 m in height. It's followed by classes 1 and 8 with 1.66% and 0.58% respectively, with class 1 associated with the outlet of the watershed and its encounter with the Mucuri River.

The TSR basin has an altimetric amplitude of 830m, with the lowest altitude point having 163 m and the highest 993m.

The class 3 is the biggest area with 27.53% of the total area of the watershed and the second one with 20.87% is class 4. The elevation classes 3 and 4 together cover an area of 1063.18 km², which represents 48.40% of the total area of the basin.

The slopes in the area of the TSR vary from 0 to 69.57% and it was divided into six classes of slope. As shown in Figure (3) and table (5) the slope class 3 (undulating relief) was predominant among the other classes, covering 49.67% (1091 km²) of the TSR watershed total area.

There were no occurrences of the class 6 (steep) in the area. As known that resolution of the raster data can interfere with morphometric parameters. Therefore, similar studies with better resolution than SRTM data in the area could improve this result in the future.

Another morphometric parameter evaluated was the aspect (slope orientation). In the aspect map of the TSR eight classes of slopes in the compass rose of the slopes were considered, as shown in figure (5C) and table (6). The northeast direction (NE) has the largest area occupying 286.85 km² (13.06% of the studied area). However, the other classes showed approximate values varying to 11.54 to 13.06%. Furthermore, the trend direction of the slopes is NE-SW in the TSR watershed.

About the drainage network, the Strahler stream order was adopted and the data was classified into five classes. These classes are represented by different colors, as shown in figure (5D). The counts of the number of channels in classes 1 to 5 are 1136, 267, 59, 12, and 1 respectively.

Table 4 – Elevation classes with area values.

Classes	Elevations (m)	Area (Km²)	%
1	< 200	36.38	1.66
2	200 – 300	402.42	18.32
3	300 – 400	604.78	27.53
4	400 –500	458.40	20.87
5	500 – 600	376.91	17.16
6	600 – 700	231.44	10.54
7	700 – 800	70.71	3.22
8	800 – 900	12.82	0.58
9	> 900	2.66	0.12
Total		**2196.53**	**100**

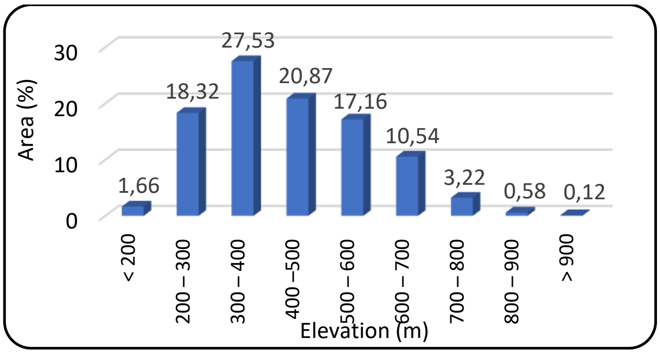

Figure 2 – Percentage distribution of the elevation classes in the watershed.

Table 5 – Distribution of slope (relief) classes.

Classes	Slope (%)	Area (Km²)	%
1	0 – 3	152.82	6.96
2	3 – 8	299.33	13.63
3	8 – 20	1091.00	49.67
4	20 – 45	647.33	29.47
5	45 – 75	6.05	0.28
6	> 75	0.00	0.00
Total		**2196.53**	**100**

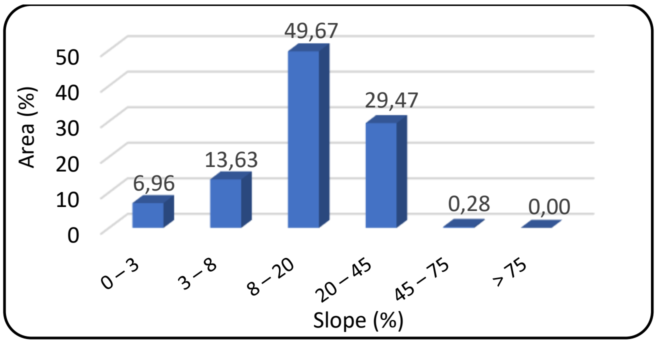

Figure 3 – Percentage distribution of slope (relief) classes in the watershed.

Table 6 – Distribution of areas according to the direction of the slope (aspect classes).

Classes	Direction	Area (Km²)	%
1 e 9	N	279.00	12.70
2	NE	286.85	13.06
3	E	278.33	12.67
4	SE	286.52	13.04
5	S	272.68	12.41
6	SW	271.22	12.35
7	W	253.40	11.54
8	NW	268.52	12.22
Total		**2196.53**	**100**

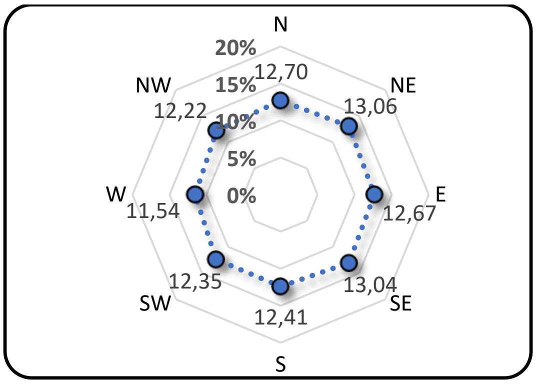

Figure 4 – Percentage distribution of the directions in the watershed.

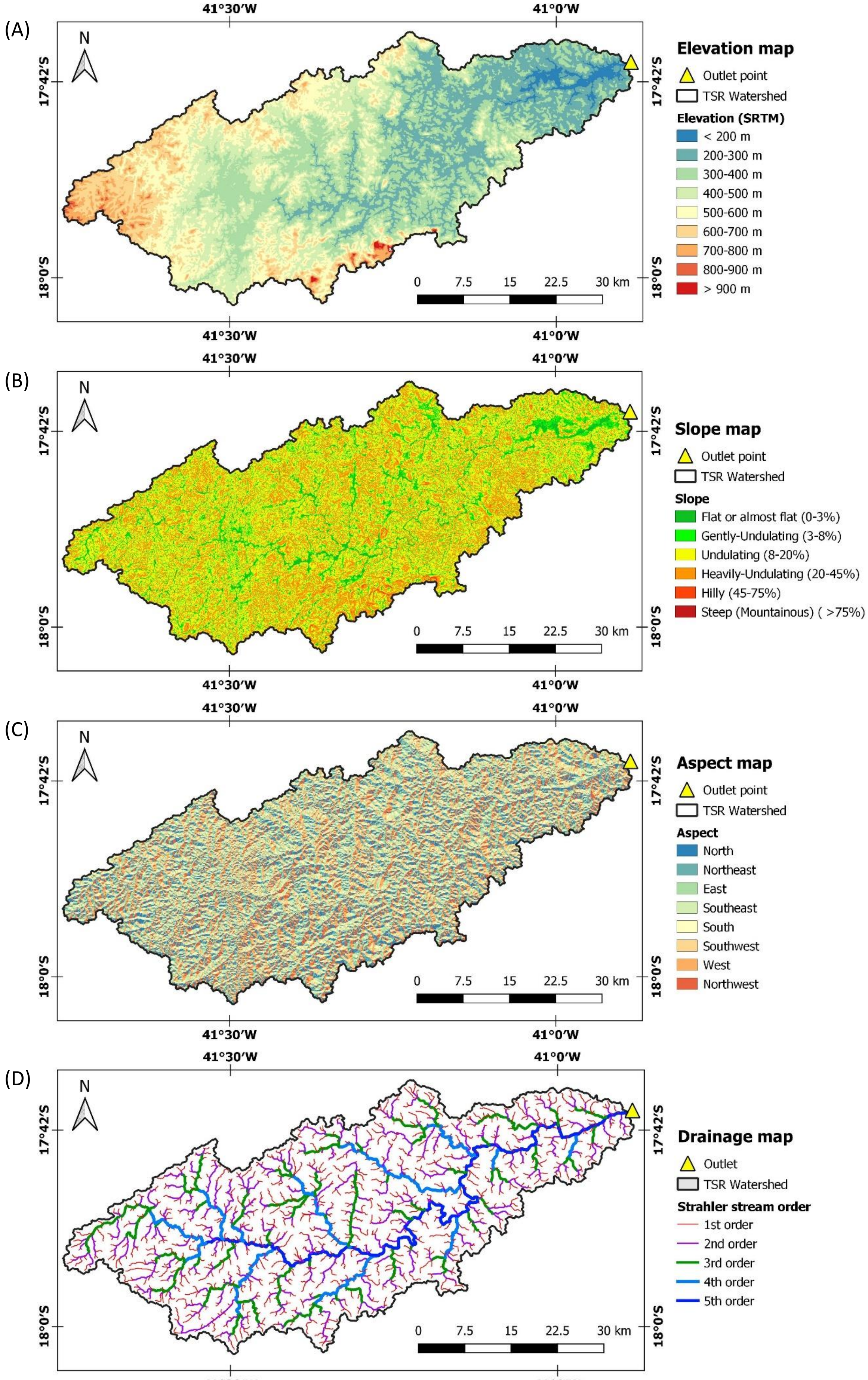

Figure 5 – Morphometric and drainage maps of the Todos Santos River Basin.
(A) Elevation map with reclassified SRTM data. (B) Slope map according to the Embrapa relief classes.
(C) Aspect map with direction orientation. (D). Drainage map with stream orders.

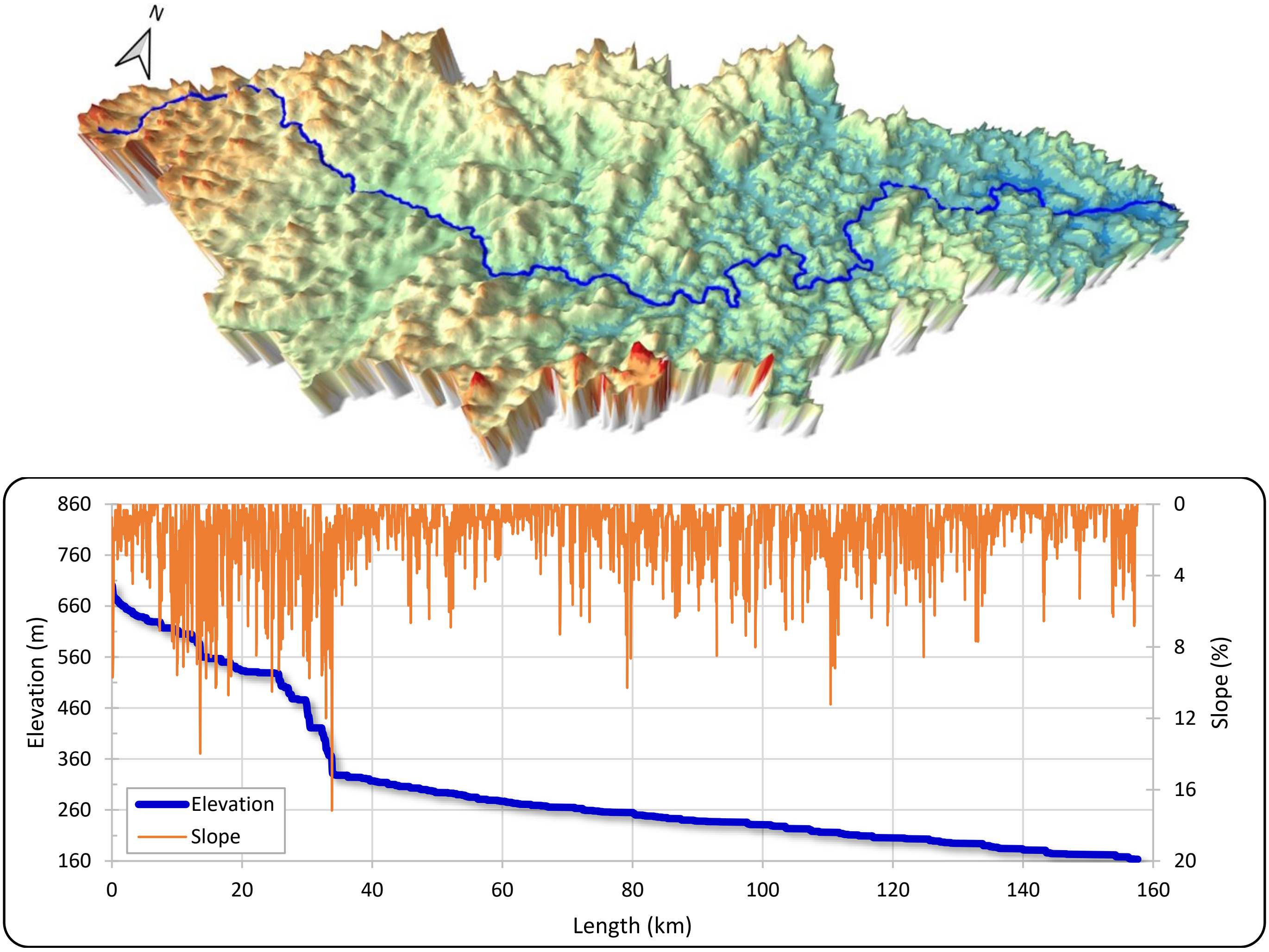

Figure 6 – 3D view of the watershed of the Todos os Santos River, the blue line indicates the main course of the river (top panel). The graph illustrates the behavior of slope and elevation along the Todos os Santos River (bottom panel).

The superficial drainage of the river basin of the Todos os Santos River flows towards the east of the basin, where it flows into the Mucuri River. However, analyzes of the slopes of the basin do not show a strong tendency for a single direction.

The drainage map shown in figure (5D) is the junction of lines that follow the lowest points of a valley, where the basin thalwegs are located (within the criteria of the minimum accumulation area to form a drainage). Moreover, each isolated point (the end of a 1st order stream) is a possible spring area, however, only a more detailed field work can confirm these possible spring areas. It is also likely that these regions could be intermittent drainage zones, where the water flow is not constant at certain times of the year.

The 3D view of the watershed of the TSR and their main course is illustrated in the figure (6). The blue line indicates de TSR and the others colors the elevations classes, in order to facilitate their interpretation.

The elevation profile along the TSR is illustrated in figure (6) and the estimated length of the TSR through the DEM was 157.63 km. Starting from the headwaters to the outlet was found a stream elevation variation of 537.55 m.

The TSR from the beginning of the stream up to 34 km in length (approximately), there was a variation of 370m in the elevation value. This zone corresponds to the headwaters of the basin and also have a higher slope variation than downstream. From this distance of 34 km to the outlet (at 157.63 km length), there is a different behavior just a few slopes are above 5%, and was calculated an elevation amplitude of 331m over a greater length.

4. Conclusion

The morphometric characterization of the Todos os Santos watershed was performed based on SRTM data. An area of 2196.53 km² was calculated for the hydrographic basin.

Based on the digital elevation model, it was possible to identify a ranging from 163 to 993 meters of elevation in the river basin, consequently, an altimetric amplitude of 830m. Moreover, the main course of the TSR has an altimetric amplitude of approximately 537.55 m. The beginning of the river has a more uneven relief in the headwaters area, followed by a more rectilinear behavior until its outlet.

The results achieved in the analysis of slopes showed that the wavy relief is predominant in the basin, covering almost 50% of the total area. Furthermore, the aspect results of the slope directions indicated a NE-SW trend.

In addition, the result of the morphometric studies in the RTS watershed may serve as a starting point for future studies in the areas of water resources, geological risks, geomorphology, civil and environmental engineering.

5. Acknowledgments

Thanks to the Jequitinhonha and Mucuri Valleys Geoscience and Engineering Study Research Group (GEOVALES) for supporting this work.

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