Nativa, Sinop, v.5, n.1, p.24-30, jan./fev. 2017.
Pesquisas Agrárias e Ambientais
http://www.ufmt.br/nativa
ISSN: 2318-7670

GRASS: A free and open source solution for hydrographic body analysis

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Recebido em junho/2016; Aceito em setembro/2016.

ABSTRACT: This work aims to describe the potentialities of a set of tools of the Geographic Resources Analysis Support System (GRASS) for hydrographic basin analyzes. For this purpose, the morphometric characterization and the definition of the drainage system of the Manso river basin, in Mato Grosso, were performed. Initially, the Digital Elevation Model (DEM) was corrected and, based on the location of the main river mouth, the morphometric parameters were calculated for the basin. It has been found that GRASS is a viable alternative for those users who cannot afford the commercially available Geographic Information Systems (GIS) and/or for those who wish to develop their models coupled to a GIS.

Keywords: morphometric characterization, morphometry, drainage, water resources, GIS.

Uma solução livre e de código aberto para análises de bacias hidrográficas

RESUMO: Este trabalho tem como objetivo descrever as potencialidades de um conjunto de ferramentas do Geographic Resources Analysis Support System (GRASS) para análises de bacias hidrográficas. Para tanto, foi realizada a caracterização morfométrica e a definição do sistema de drenagem da bacia do rio Manso, em Mato Grosso. Inicialmente, procedeu-se com a correção do Modelo Digital de Elevação (MDE) e, a partir da localização da foz do rio principal, foram calculados os parâmetros morfométricos para a bacia. Verificou-se que o GRASS é uma alternativa viável para aqueles usuários que não podem arcar com os Sistemas de Informações Geográficas (SIGs) disponíveis comercialmente e/ou para aqueles que desejam desenvolver seus modelos acoplados a um SIG.

Palavras-chave: caracterização morfométrica, morfometria, drenagem, recursos hídricos, SIG.

1. INTRODUCTION

Defined as a surface circumvented by topographic dividers, where precipitated water and springs flow superficially to and through a common hydrographic network, the basin has a main watercourse that has an identifiable mouth. From the location of the mouth of the main river, it is possible to identify the hydrographic network and the higher areas that surround the water courses of the basin, called "watershed" (SPANGHERO et al., 2015).

In Brazil, the river basin is legally established as a territorial unit for the implementation of the National Water Resources Policy and for the performance of the National Water Resources Management System, and the establishment of this unit involves the application of its instruments as a framework of water bodies, with granting and charging for the use of water resources (DE FREITAS et al., 2012). Albuquerque; De Souza (2016) state that the definition of the river basin as a unit for the analysis of environmental systems is the most adequate, starting from the perspective of the tripod formed by the environmental, social and economic dimension, since their morphology aggregate, systematically, the actions of nature and society.

For many years, river basin study has been developed manually through printed topographic maps. However, due to advances and technological improvements in the computational area, Geographic Information Systems (GIS) have become the most used tools for the morphometric characterization of hydrographic basins, adding speed and accuracy to the environmental studies.

Often, proprietary commercial packages are used for automatic processing in a GIS environment. However, the use of free and open source software has been increasing, which has shown promising potential for the management of water resources (CASTRO et al., 2015; FAN et al., 2015; SWAIN et al., 2015; FANTINEL; BENEDETTI, 2016). Currently there are several free software for GIS, ranging from desktop systems capable of analyzing data and compose printed maps to database systems for the purpose of storage and management of geographic data.

For Bunting et al. (2014), examples of this type of software are Orfeo Toolbox, OSSIM tools, GRASS GIS, Geospatial Data Abstraction Library – GDAL, SAGA GIS, Opticks, Terrain Analysis using Digital Elevation Models – TAUDEM, the Raster Input/Output Simplification Python library, the Sorted Pulse

Data software library, PostGIS, PolSARPro, QGIS and others. According to Neteler et al. (2012), GRASS GIS stands out as the free application with longer development time, provided with powerful spatial analysis tools.

The present work aims to describe the potentialities of a set of tools of the Geographic Resources Analysis Support System (GRASS) for hydrographic basin analyzes. For this purpose, the drainage area of the Manso River in Mato Grosso - Brazil, was defined as a unit to be studied because of its regional importance.

2. MATERIAL AND METHODS

2.1. Study area

The territory of Mato Grosso State is divided into 27 Planning and Management Units – UPGs in Portuguese. The Manso river basin (MRB) has an area of 10,773 km², and is inserted in the UPG Alto Cuiabá P-4, in the Center-South region of the State of Mato Grosso, as shown in Figure 1.

The Manso River is one of the main formers of the Cuiabá River, which in turn is a tributary of the left bank of the Paraguay River, and thus participates significantly in the hydrological system of the waters of the Alto Paraguay/Pantanal basin (SANTOS, ALVES, 2014) . The rivers Palmeiras, Roncador, Casca and Quilombo are its main contributors, and also formers of the Multipurpose (MP) Manso Lake.

Distant from Cuiabá, about 100 km, the Manso reservoir has approximately 427 km² of wetland for maximum height and has been subject to silting problems due to erosion from the headwaters of the main river. It was designed with the main objectives of regulating the level of the Cuiabá River (avoiding floods) and generating electricity (XAVIER et al., 2010).

The drainage of the Manso River is embedded in a region that has undergone transformations in the land use and occupation patterns, which makes it susceptible to environmental impacts. Le Strat et al. (2011) point out that there was a significant evolution between 1992 and 2009 of the areas occupied by agricultural production (almost 108%) and that, due to this increase associated with the formation of the MP Manso Lake, there was a reduction of approximately 38% of the areas covered by natural vegetation of Cerrado and Forests.

The Manso River Basin can be divided into three geomorphological units namely the *Planalto Central* of Mato Grosso, the *Província Serrana* and the *Baixada Cuiabana* (ANDRADE et al., 2008).

The study area is subject to the Equatorial and Hot Tropical Climate domain, with a small annual seasonal thermal variation (IBGE, 1989).

2.2. Methodological procedure

The characterization of the Manso river basin was performed based on the interpretation of the Digital Elevation Model (DEM) based on SRTM data (USGS, 2015). The GRASS - Geographic Resources Analysis Support System - version 7.03 (GRASS DEVELOPMENT TEAM, 2016) was used for processing in digital environment, which allowed manipulation, editing, reading and presentation of the data. The methodological procedures were developed in three stages: i) preliminary processing of the DEM; ii) DEM analysis processing and; iii) processing of data collection.

2.2.1 Preliminary processing of the DEM

In some regions of the DEM, there were places with imperfections where the colors were not smoothed as one would expect, but abrupt, without information. For Grohmann (2008), these anomalous values represent voids in the data, and can be caused by water bodies or failures in the return of the Radar signal, especially in areas of high slope (Figure 2).

As a first step of the study, we proceeded to fill these voids of the DEM by using the command *r.fillnulls* (NETELER,

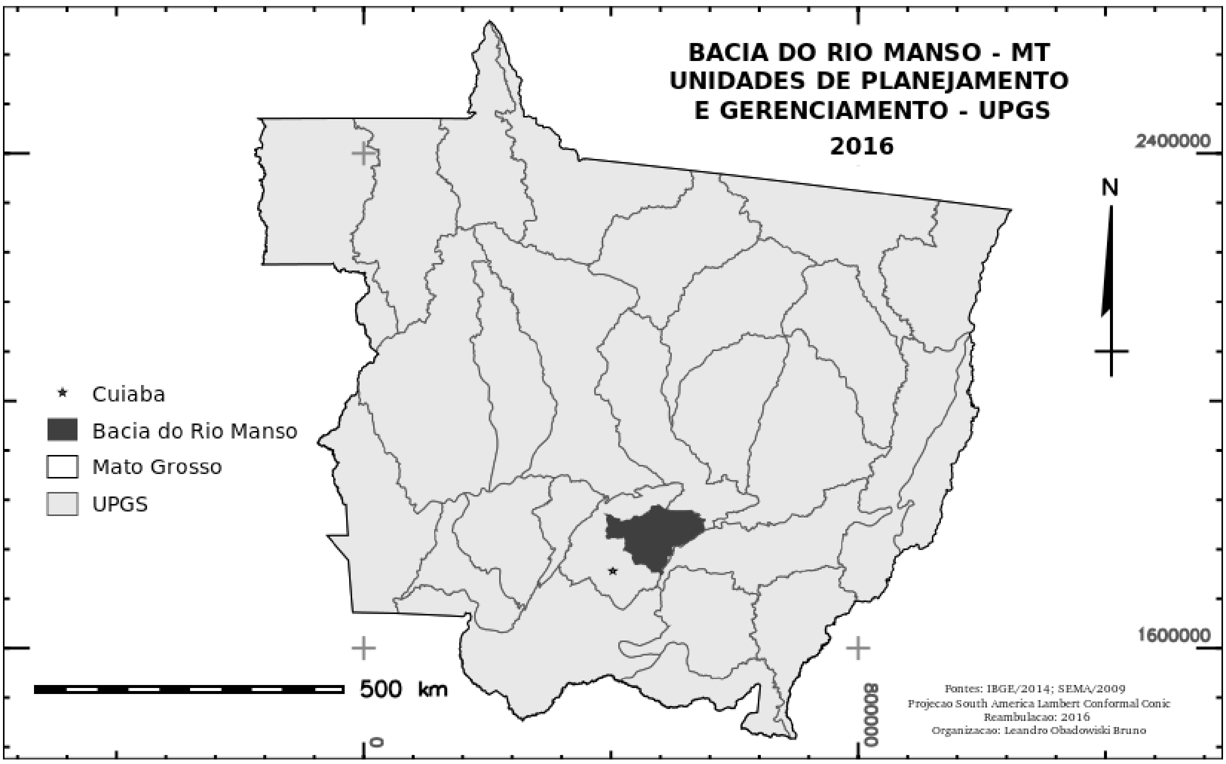

Figure 1. Map of the location of the Manso River basin in Mato Grosso State.
Figura 1. Mapa de localização da bacia hidrográfica do Rio Manso em Mato Grosso.

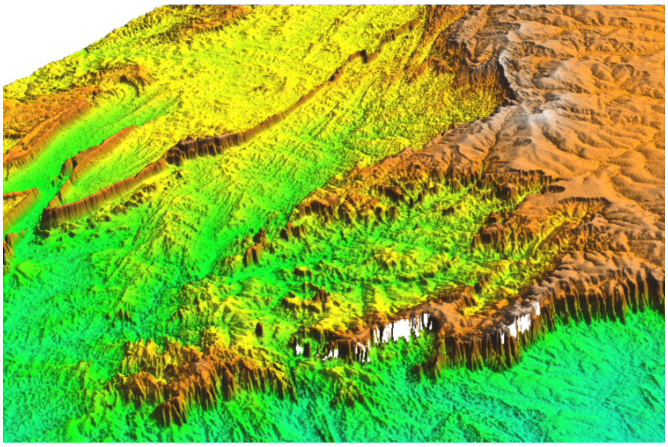

Figure 2. DEM corresponding to the study area, obtained in the U. S. Geological Survey.
Figura 2. MDE correspondente à área de estudos, obtido no *U. S. Geological Survey*.

2005), opting for the interpolation algorithm by Regularized Splines with Tension (RST) (MITASOVA; HOFIERKA, 1993; MITASOVA; MITAS, 1993).

After filling the voids of the raster, a refinement of the DEM was performed from the removal of the spurious depressions (Figure 3). For this procedure, the tool *r.fill.dir* (SRINIVASAN, 2008) was implemented, which combines both the effort to maintain the hydrographic characteristics and the removal of spurious data related to regions of depression or elevations (HUTCHINSON, 1989), as the depressions in the DEM prevent the superficial runoff of the water, generating imperfections in the model and damages to the definition of the flow, which must be directed downstream of the hydrographic basin.

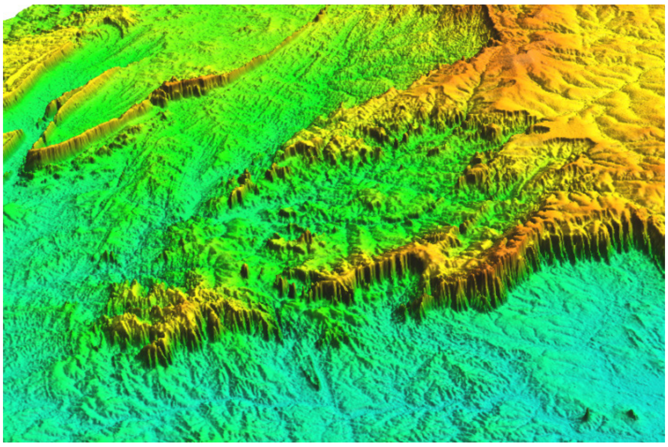

Figure 3. DEM corresponding to the study area after correction of the void data and filling of the spurious data.
Figura 3. MDE correspondente à área de estudos, após correção dos vazios dos dados e preenchimento dos dados espúrios.

2.2.2 DEM analysis processing

After the initial stage of data correction, we proceeded with the DEM analysis processing. In this step, the flow direction was obtained by using the MFD method (multiple flow direction), which allowed the definition of the basic drainage system for the next stage (JENSON; DOMINGUE, 1988; JASIEWICZ; METZ, 2011).

2.2.3 Processing of data collection

In order to obtain the data, the DEM and the geographic coordinates corresponding to the exudation of the basin are used, and it is necessary to define a threshold value for the formation of the microbasins, which was 1 km².

In the execution of this step the module *r.basin,* developed by Di Leo; Di Stefano, (2013), is used, in which several hydrological tools are executed simultaneously, known as **r.streams* (JASIEWICZ; METZ, 2011). As a result, the accumulated flow calculation is performed, the basin boundaries are delimited, and the drainage network is drawn through the DEM. Based on these maps, hydrologically significant form factors and morphological parameters, such as topological diameter, drainage density, Horton indexes, concentration time and other statistics of the drainage system, such as mean and maximum elevation, geometric characteristics, centroid coordinates, rectangle containing the basin, etc., are also calculated. Figure 4 shows the main methodological steps addressed in this study.

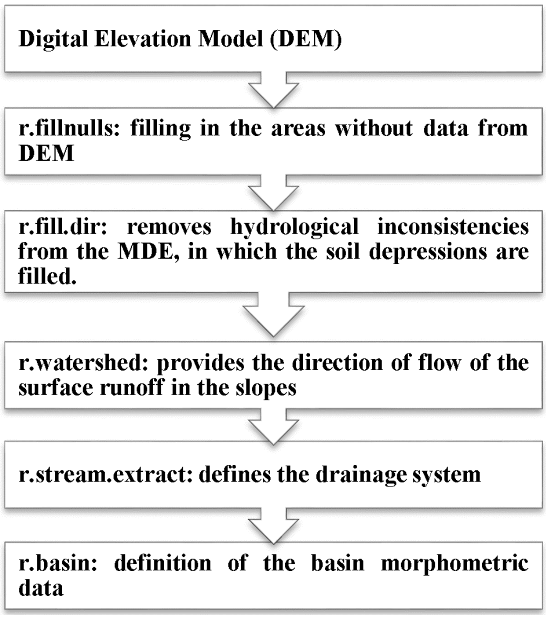

Figure 4. Methodological procedure adopted for the delimitation of the Manso river basin.
Figura 4. Procedimento metodológico adotado para a delimitação da bacia do rio Manso.

2.3. GRASS

Geographic Resources Analysis Support System - (GRASS) is free and open source software for GIS application used worldwide. It can combine multiple modules at the same time in a single analysis, enabling automated execution. In addition, it may be combined with other software packages for statistical analysis and GIS Web applications. A series of studies have demonstrated the potential of GRASS.

Rocchini et al. (2013) presented the module *r.diversity* with the purpose of calculating the diversity index of species for different spatial scales. Radinger et al. (2014) described the module *r.fidimo* that simulates the dispersion of fishes in a drainage system taking into account several aspects, such as heterogeneity, species, size and even natural barriers. In a case study, Dobrowski et al. (2009) used a solar energy algorithm, the module *r.sun*, to quantify the absolute and relative influence of the physiographic factors of the landscape scale on the measurement of regional temperatures and to evaluate how these influences vary over time. Andreo et al. (2015) studied the spatial and temporal variations of blooms of chlorophyll-a and phytoplankton concentration in the Argentinean Patagonia region using an 11-year time series of MODIS/Aqua level 3 (L3) chlorophyll product images. In the aforementioned studies, GRASS conferred excellent robustness and flexibility, contributing to satisfactory results for these applications. Figure 5 shows the work environment of the Geographic Resources Analysis Support System – (GRASS).

3. RESULTS

The methodological procedure adopted allowed to verify that the Manso river has its springs located in the region of the *Planalto dos Guimarães*, at altitudes no higher than 904 meters. The main river runs approximately 321 km in length with an average slope of 1.15% until it flows into the Cuiabazinho River, at a height of 197 meters (Figure 6). The basin has approximately 10,773 km², being the main tributary of the Cuiabá river. Table 1 presents the main morphometric parameters obtained in this study.

4. DISCUSSION

The complement *r.basin* is a tool developed for the GRASS environment, which allows the automatic definition of the main

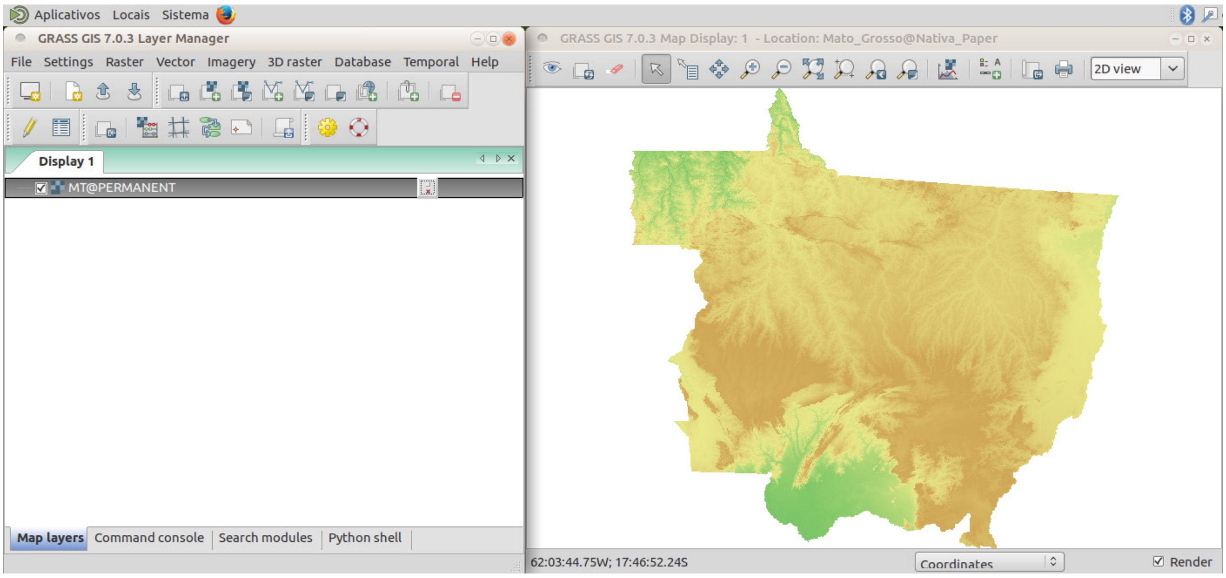

Figure 5. Work environment of the GRASS GIS.
Figura 5. Ambiente de trabalho do GRASS GIS.

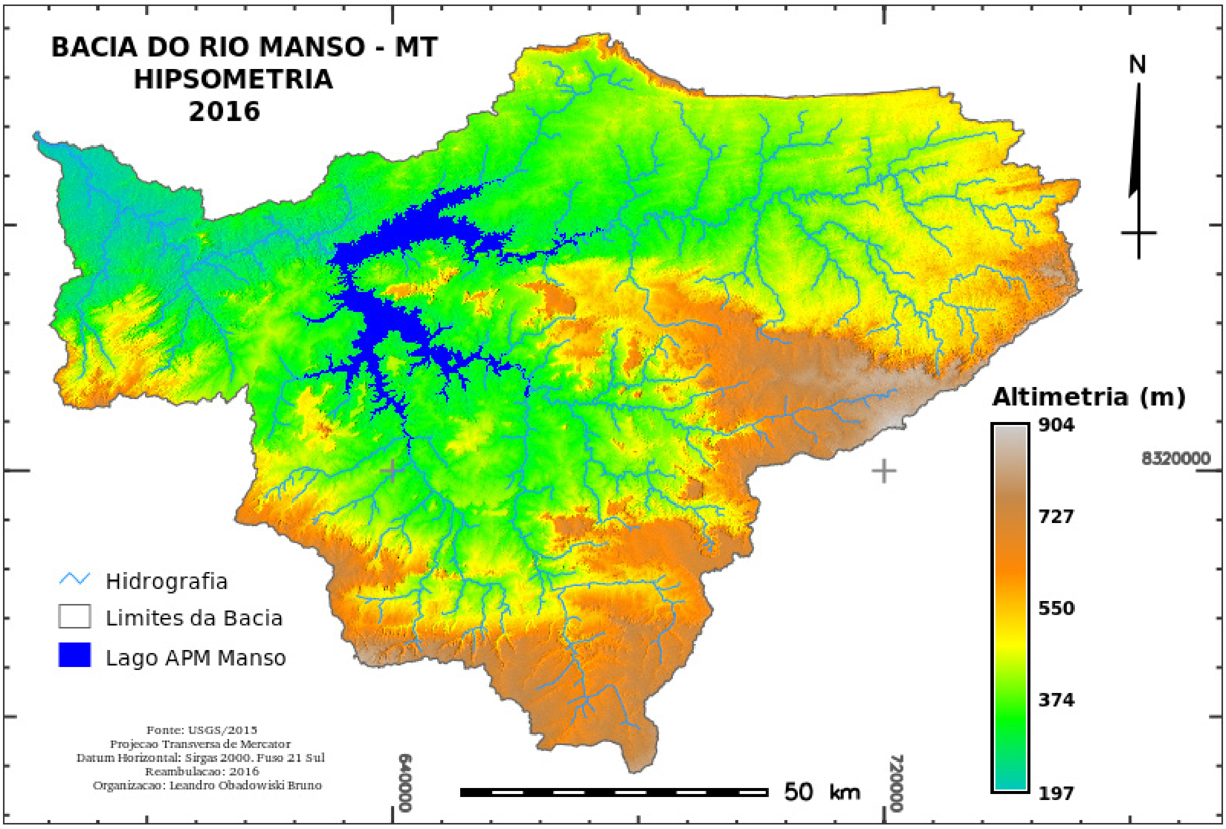

Figure 6. Altimetry of the Rio Manso basin.
Figura 6. Mapa de Altimetria da bacia hidrográfica do Rio Manso.

Table 1. Main morphometric characteristics obtained in the study.
Tabela 1. Principais características morfométricas obtidas no estudo.

Morphometric characteristics	
Drainage area (km^2)	10,773.46
Perimeter (km)	800.58
Length of main river (km)	321.69
Average slope of the main river %	1.15
Total length of rivers (km)	7,635.61
Total number of rivers in the basin	4,862.00
Order of the basin	7
Density of drainage ($km.km^{-2}$)	0.70
Average slope of the basin	4.92
Maximum altitude (m)	904
Minimum altitude (m)	197
Altitude difference (m)	707
Relationship of circularity (Rc)	0.36
Compactness coefficient (kc)	6.83
Form factor (Ff)	33.48
Circularity index (CI)	0.21
Concentration time (h)	42.20

morphometric parameters of a river basin from the digital elevation model and the geographical coordinates of the exudation section. The user also needs to define a prefix for the output files and a directory where the user wants to store the results and statistics generated in this processing step, as shown in Figure 7.

The use of the module *r.basin* makes it simpler for students, engineers and researchers to carry out studies on river basins, since it provides an automated execution between several existing GRASS modules for hydrogeomorphic processing. As main features of this tool, we can highlight:

- Extraction of the drainage system of a digital elevation model according to the criteria defined by the user (*r.stream.extract*);
- Definition of the physical characteristics of the drainage system by using calculations and statistics by Strahler, Horton, Shreve and Hack for the hierarchy of the drainage system (*r.stream.order*);
- Advanced modeling of river basins (*r.stream.basins*);
- Calculation of the distance of the waterbodies in relation to the exudate; calculation of the relative elevation of the drainage system and its slope (*r.stream.distance; r.stream.slope*);
- Definition of the geometric properties of drainage systems, for example, the calculation of the length of the main river and flows of the tributaries (*r.stream.channel; r.stream.segment*);

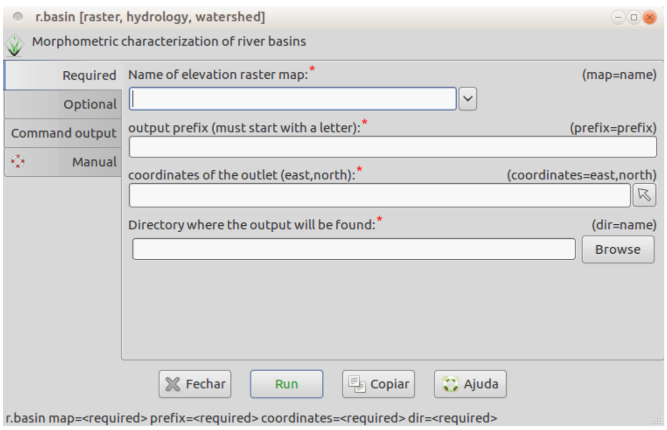

Figure 7. Graphical user interface (GUI) for *r.basin*.
Figura 7. Interface gráfica do módulo *r.basin*.

- Characterization of the main morphometric features of the basin, exported to the directory defined by the user, through the following categories: i) vector files: river basin, main river, drainage and exudation system; ii) matrix files: slope, aspect, flow direction, accumulated flow, distance of the exudate, slopes, and drainage system according to classification proposed by Strahler, Horton, Shreve and Hack;
- Extraction of the morphometric parameters of the river basin and the drainage system through a file in format (.CSV) exported to a directory defined by the user (*r.stream.stats*), according to Figure 8.

A detailed documentation for all the modules explored in this work is also worth noting, often accompanied by scientific references (OSGEO, 2016).

This is a relevant point for the user, since it facilitates the foundation and the theoretical basis of the subject under study. It should be noted that GRASS is defined as a free and open source computing program, which is an important asset, as it allows not only adaptation to the needs of a given study through customizations and improvements made possible by access to the its source code, but also encourages the promotion and sharing of knowledge for its users.

Milaré et al. (2016), when considering the many advantages of adopting a large-scale free software in the country, emphasized that managers could and should encourage its use so that the use of free software produces the economic and social benefits that are characteristic of it.

The ordering of the watercourses allowed the characterization of the hierarchy of the river channels and of the degree of branching of the drainage system of the basin automatically. According to the ordering proposed by Strahler (1957), which establishes a successive increase of the order number along a given drainage system, 4,862 bodies of water were identified, encompassing rivers of up to the 7th order of drainage. This first parameter has a direct influence on the drainage density index, referenced by Villela; Mattos, (1975) as indicative of the degree of development of a drainage system, with values ranging from 0.50 km/km^2 in basins with poor drainage to 3.5 km/km^2 for exceptionally well-drained basins. For this survey, the value

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Morphometric parameters of basin:

Easting Centroid of basin,664095.00
Northing Centroid of basin,8343255.00
Rectangle containing basin N-W,"('581460', '8391210')"
Rectangle containing basin S-E,"('752190', '8270730')"
Area of basin [km^2],10773.462375
Perimeter of basin [km],800.58533285742
Max Elevation [m s.l.m.],904.0
Min Elevation [m s.l.m.],197.0
Elevation Difference [m],707.0
Mean Elevation,455.3928
Mean Slope,4.92
Length of Directing Vector [km],87.6525769994355
"Prevalent Orientation [degree from north, counterclockwise]",0.3720681550823805
Compactness Coefficient,6.83557291665713
Circularity Ratio,0.2112272303957015
Topological Diameter,330.0
Elongation Ratio,0.36407220792351735
Shape Factor,33.48961214927882
"Concentration Time (Giandotti, 1934) [hr]",42.20301194659075
Length of Mainchannel [km],321.695644816
Mean slope of mainchannel [percent],1.1561878369521659
Mean hillslope length [m],22912.84
Magnitudo,3396.0
Max order (Strahler),       7
Number of streams,      4862
Total Stream Length [km],    7635.6119
First order stream frequency,0.3152189966227083
Drainage Density [km/km^2],0.7087426153469999
Bifurcation Ratio (Horton),  4.1418
Length Ratio (Horton),  2.2661
Area ratio (Horton),   4.4466
Slope ratio (Horton),  1.2668
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Figure 8. File format (.CSV).
Figura 8. Arquivo em formato (.CSV).

obtained was 0.7 km/km², indicating, therefore, that the Manso river basin is characterized by the regular drainage capacity.

Similar data were also observed by Cândido; Santos, (2011), who studied the Manso River basin using the ArcGis software developed by the ESRI (Environmental Systems Research Institute), based on a TOPODATA DEM, and obtained 44 second-order drainage sub-basins and 11 fourth-order drainage rivers, indicating that both the second-order and fourth-order sub-basins of the Manso river present low drainage density and low frequency of rivers, which favors infiltration under normal precipitation conditions.

The studied area also showed little susceptibility to flooding under normal conditions of precipitation, considering that the resulting compactness coefficient was a value away from the unit (6.83) and, because the circularity index had an extremely low value (0.21), corroborating with the results obtained by Andrade et al. (2008).

For Tonello et al. (2006), the slope is relevant in planning, both for compliance with environmental legislation, and to ensure the efficiency of man's interventions in the environment and influencing the distribution of water between surface and ground runoff. This factor is related to the measurement of susceptibility to soil erosion. By using the ArcGis software, Xavier, (2009); Xavier et al. (2010) obtained a value of 10,553 km² in the Manso river basin, with a predominance of flat relief (0 to 3%), a composition of approximately 70% of the basin. For the present study, the mean slope of the basin was 4.92.

Among the analyzed morphometric characteristics, the form factor (33.48) was the only one that presented discrepant values of the other studies conducted in the Manso river basin. For this reason, this morphometric parameter should be obtained according to the methodology detailed by Da Cunha e Silva et al. (2016), replacing the value obtained with the GRASS module *r.basin*, in order to obtain a value between 0 and 1, according to the proposal of Villela; Mattos, (1975).

5. CONCLUSIONS

The analysis of the data and the interpretation of the obtained results allowed concluding that the Manso river basin has an elongated form, evidencing a lower risk of floods in normal conditions of annual rainfall.

The obtained results did not present significant disagreements with those obtained in other modalities of morphometric characterization applied in the Manso river basin, revealing that the methodology used is feasible and consistent for the evaluation of watersheds.

GRASS offers many features provided by native features and complements as a viable alternative for those users who cannot afford commercially available Geographic Information Systems and/or for those who wish to develop their GIS-coupled models.

6. ACKNOWLEDGMENTS

We thank to the Ministry of Environment of Mato Grosso (SEMA/MT) and to the GRASS developers.

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