Morphometric characterization of Mestre Campo Stream Watershed, in Piranga City, Minas Gerais

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Abstract

The multiple environmental dynamics of watersheds make these natural spaces interesting objects of study, and in areas with few scientific investigations, such as the Mestre Campo Stream watershed, the need for these investigations is even greater. The accomplishment of this paper sought to characterize the morphometry of Mestre Campo Stream Watershed, located in Piranga City, Minas Gerais, Brazil, as a first activity to create a management plan for the natural resources available in the area. Therefore, TOPODATA geomorphological data were used in a geographic information system (GIS) to extract the morphometric information – area and respective perimeter, length of axis and of drainage network – from the study area and, then, these variables were used to estimate the following indicators: form factor, circularity and compactness indexes, elongation ratio and drainage density, in order to describe the watershed. The morphometric indexes indicated an elongated behavior for the watershed, characterizing it as a space of low susceptibility to flooding under normal precipitation conditions. In addition, the drainage network showed fourth-order ramifications and a median capacity of drainage. The sub-watersheds that makes the Mestre Campo Stream Watershed were also characterized, the Sub-watershed of Brum Stream presented a rounded shape, while the Alto Mestre Campo Sub-watershed presented elongated characteristics. These results highlight the heterogeneity of Mestre Campo Stream Watershed, which must be considered when elaborating the management plan for the studied watershed, respecting the particularities of that geographic space in order to properly explore its natural resources.
Keywords: Environmental management. Shape indexes. GIS.

Introduction

The watershed can be understood as a physical, natural and open system that captures a volume of precipitated water and, through its sloping surfaces, conducts the volume and other materials present in the area to the watershed mouth (CHRISTOFOLETTI, 1980; COELHO NETO, 1995; SILVEIRA, 2001). This geographical space is occupied by several organisms – such as soil, fauna, flora,

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water courses and communities – and the structuring and the interaction of these elements within the watershed make this natural area an interesting object of study.

The Mestre Campo Stream watershed, area of study of this paper, is a natural space located in Piranga city, Minas Gerais administrative area, Brazil, and there is only a few scientific studies describing the local. Data survey on the environmental dynamics of the watershed would be very important for the management of that ecological unit, in order to plan the actions according to the area capability (PORTO; PORTO, 2008), accounting the rational and sustainable use of natural resources.

In this context, the study of the watershed morphometry is one of the first procedures in environmental area in order to survey the existing natural potential; furthermore, the technical information can be the basis for planning and managing actions. The combination of morphometric parameters – such as the drainage area of watershed, the perimeter, the length of axis and the length of its drainage channels – allows the estimation of specific indicators for the local – for example, the form factor, indexes of circularity and of compactness, elongation ratio and drainage density – and make it possible to study the environmental and anthropic vulnerability of watersheds (LIMA et al., 2011; RODRIGUES et al., 2016).

Sousa (2016), when studying the Tapuio River watershed, in Ceará administrative area, Brazil, concluded that the survey of morphometric characteristics resulted in important analyzes that revealed low propensity for flooding in the studied watershed. Coutinho et al. (2011), studying the Prata River watershed, located in south of Espírito Santo administrative area, Brazil, also found that the watershed presented morphometric indices of little tendency to flooding, disregarding abnormal occurrences of precipitation.

Silva et al. (2018), analyzing morphometric data from the Rangel Stream watershed, one of main tributaries of Gurguéia River, which supplies the entire southern of Piauí administrative area, Brazil, characterized the watershed as medium sized, not very favorable to flooding, with high soil permeability, of straight and low gradient channels. The authors concluded that morphometric analyzes are indispensable elements for planning and assessing hydrological behavior of watershed, assisting in decision making on conservation, use and occupation of land.

Therefore, physical characteristics play an important role on the hydrological cycle of watersheds, influencing infiltration, surface and subsurface produced runoff, evapotranspiration, among others (RODRIGUES et al., 2008). Computational tools have been great allies in morphometric studies of natural spaces, as reported by Antoneli and Thomaz (2007).

Geographic information systems (GIS), such as Quantum GIS, have been well accepted in watershed studies, facilitating the extraction of characteristics, the visualization of observations and the modeling and correlation of data (CARDOSO et al., 2006; TRENTIN et al., 2015; CAETANO; CASAROLI, 2016).

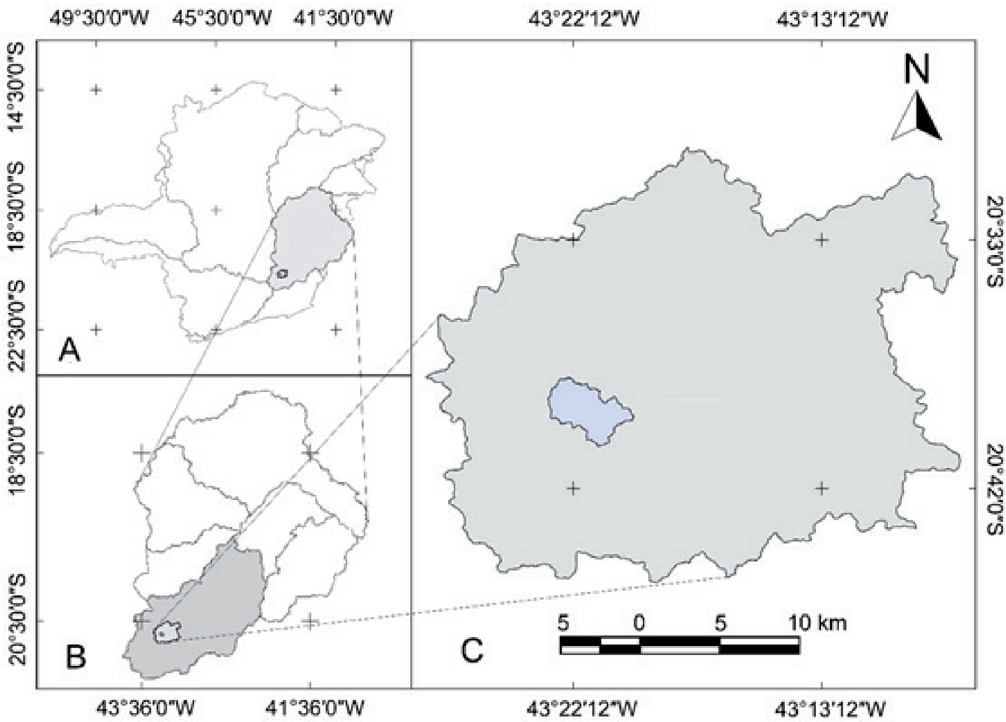
In this context, the present paper aimed mapping the morphometry of Mestre Campo Stream watershed, in Piranga city, Minas Gerais administrative state, Brazil, as a potential tool to support a master plan for managing the natural resources present in the area.

Material and methods

Characterization of the studied area

The studied area comprised the watershed of Mestre Campo Stream, located west of Piranga City, administrative region of Minas Gerais, Brazil. With 13.93 km^2 , the area is located between the geographical latitude coordinates 20°37’58’’ and 20°40’31” South, and longitude coordinates 43°21’17” and 43°22’21” West, as shown in Figure 1.

Figure 1 – Geographic location of Mestre Campo Stream watershed in Minas Gerais (A.), in relation to the federal watershed of Rio Doce (B.) and to Piranga City (C.).



Source: Elaborated by the authors (2018).

The watershed under study has the Mestre Campo stream as the main water channel, which is, in turn, a tributary of Piranga river. When Piranga River merges with the Carmo River, it forms Doce River, known as one the largest watersheds in the state of Minas Gerais. The predominant soil type in watershed is the red-yellow latosol, according to the Digital Soil Map prepared by EMBRAPA Solos (SANTOS et al., 2013), the predominant vegetation is composed of semideciduous seasonal rain forests, which fall within the domains of the Atlantic Forest (SOBRINHO et al., 2009).

The regional climate of watershed is tropical in altitude, with hot and rainy summers, dry winters, and moderate temperatures, receiving the designation Cwa in Köppen classification (LACERDA, 2014). The average temperatures recorded are between 12ºC and 33ºC (NASCIMENTO; CASTRO, 2013).

To carry out the proposals presented here, the paper was divided in two stages, which are:

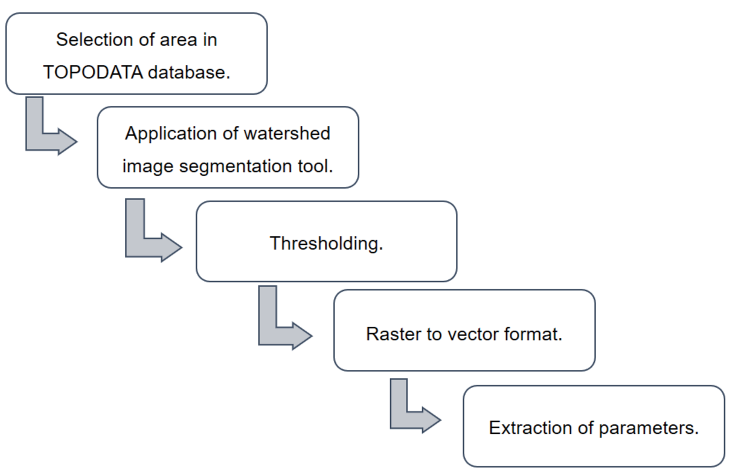
A. Mapping of morphometric data;
B. Analysis and interpretation of results.

Mapping of morphometric data

Geomorphometric data of the area under study, available in Remote Sensing Division of Brazilian Institute for Space Research (INPE), were used in morphometric analysis of Mestre Campo Stream watershed. This database, known as TOPODATA, is corrected by INPE before being shared with the user and it is suitable for regions of rugged relief, such as Piranga City (LANDAU; GUIMARÃES, 2011), which supports its choice for this study.

The watershed technique of digital image segmentation was applied to the TOPODATA database for the delimitation of Mestre Campo Stream watershed and, on that output, the threshold method (cutoff value equal to 50) was used in order to define the drainage channels of the studied area. The raster data of delimited watershed and of demarcated drainage channels were converted to vector format and, then, it was extracted the variables area, the perimeter of watershed, the length of main axis, and the length of the drainage network. Figure 2 illustrates the methodology used to obtain the morphometric parameters of Mestre Campo Stream watershed.

Figure 2 – Experimental configuration used to extract the morphometric parameters of Mestre Campo Stream watershed.



Source: Elaborated by the authors (2018).

The morphometric parameters (area, perimeter, length of axis and length of drainage channels) observed were used, via physical indicators, to classify the watershed in terms of its shape and its natural drainage system. In this context, the compactness coefficient (Kc), circularity index (Ic), form factor (F), elongation ratio (Re), basin order, bifurcation ratio (Rb) and drainage channels density were estimated, all parameters are detailed in the following paragraphs.

Compactness coefficient (Kc) and circularity index (Ic)

The compactness and circularity indices were estimated using Equations 1 and 2, described mathematically below, according to Cardoso et al. (2006).

$$Kc = 0.28\ P / A^{0,5} \quad (1)$$

$$Ic = 12.57\ A / P^{2} \quad (2)$$

at which:

Kc and Ic are the compactness and circularity coefficients, respectively, and they are dimensionless;

P is the perimeter of watershed, in km;

A is the drainage area of watershed, in km^2.

The values of Kc and Ic supported the morphometric classification of watershed and the discussions. Kc values are always higher than the unit, and indices between 1.00 and 1.25 denote watersheds of a rounded shape; Kc between 1.25 and 1.50 describe oval areas, and values greater than 1.50 indicate elongated watersheds. On the other hand, the values of Ic oscillated between zero and the unit, in which watersheds of rounded shapes tend to unitary indexes, and values close to zero characterize elongated shapes for the area (CARDOSO et al. 2006).

Form factor (F) and elongation ratio (Re)

The form factor, similar to the circularity index, presents values between null and the unit, in which F lower than 0.50 indicates elongated watersheds, values from 0.50 to 0.75 characterize a medium tendency to flooding and over 0.75, areas of rounded characteristics and subjected to flooding (VILLELA; MATTOS, 1975). The F index was estimated using Equation 3 (CARDOSO et al, 2006).

$$F = A / L^2 \qquad (3)$$

at which:

F corresponds to the form factor, dimensionless;

L is the length of main axis of watershed, in km.

The elongation ratio (Re), described mathematically by Equation 4, presents high values for watersheds of rounded characteristics and susceptible to flooding, and lower indexes for natural areas of elongated shapes and less susceptible to flooding (MOSCA, 2003; FERRARI, 2013).

$$Re = 1.128\, A^{0,5} / L \qquad (4)$$

Aher et al. (2014) classify the watersheds as elongated in shape when the Re values are between 0.60 and 0.79; those with an index greater than 0.89 are qualified as oval.

Basin order, bifurcation ratio (Rb) and drainage density (Dd)

The order of water courses and the bifurcation ratio (Rb) express the degree of branching of the watershed drainage system (TUCCI, 2001); the larger the ramification, the greater the tendency for the wathershed flooding peak. This paper used Strahler's method (1952) to analyze the basin order, and Equation 5 (CAMPANHARO, 2010) to estimate the bifurcation ratio of each order.

$$RbO = Nc / Nc_{+1} \qquad (5)$$

at which:

RbO is the bifurcation ratio of each order, dimensionless;

Nc is the number of channels of a given order;

Nc_{+1} corresponds to the number of channels in the next higher order.

The bifurcation ratio for the watershed was estimated by Equation 6 (HORTON, 1945).

$$Rb_{BH} = \Sigma \ RbO / N_{RbO} \qquad (6)$$

at which:

RbBH is the bifurcation ratio of watershed, dimensionless;

NRbO corresponds to the RbO number of watershed.

Lima (2018) mentions that the bifurcation ratio varies from 2.0 to 4.0 for most watersheds. The higher the bifurcation ratio, the greater the ramification degree of drainage channels of a watershed, and the greater the tendency for flooding peak (CARVALHO; MELLO; SILVA, 2006).

The drainage density of watershed (Dd), determined by Equation 7 (CARVALHO; MELLO; SILVA, 2006), reveals the relationship between the total length of watershed water courses and its total area. Dd values classified as low represent low capillarity and they can affect the risks of flooding, the time of concentration and the risks of serious erosion along water courses (STRAHLER, 1957).

$$Dd = \Sigma L / A \qquad (7)$$

at which:

Dd consists of drainage density, in km km^{-2};

ΣL is the sum of all channels present in watershed, in km.

According to Villela and Mattos (1975), this index varies on 0.5 km km^{-2} for watersheds of poor drainage and on 3.5 km km^{-2} or more for very well drained watersheds.

It is worth noting that all the process described graphically on Figure 2 was carried out by the geographic information system QGIS 2.18 (QGIS, 2011) and the GRASS GIS 7 internal library.

Analysis and interpretation of results

The results analysis was based on quantitative and qualitative parameters. The seven morphometric indices estimated – compactness coefficient, circularity index, form factor, elongation ratio, basin order, bifurcation ratio and drainage density – in addition to the charts and maps were the references for quantitative assessments. The quantitative data obtained were compared with each other and with the relevant literature aiming to characterize the hydrological behavior of the studied watershed.

Additionally, visits to watershed allowed the diagnosis of use and occupation of natural space. This diagnosis supported the data qualitative analysis and it contributed to the accomplishment of the proposed approaches, which were supported by the literature.

Results and discussion

Mestre Campo Stream watershed

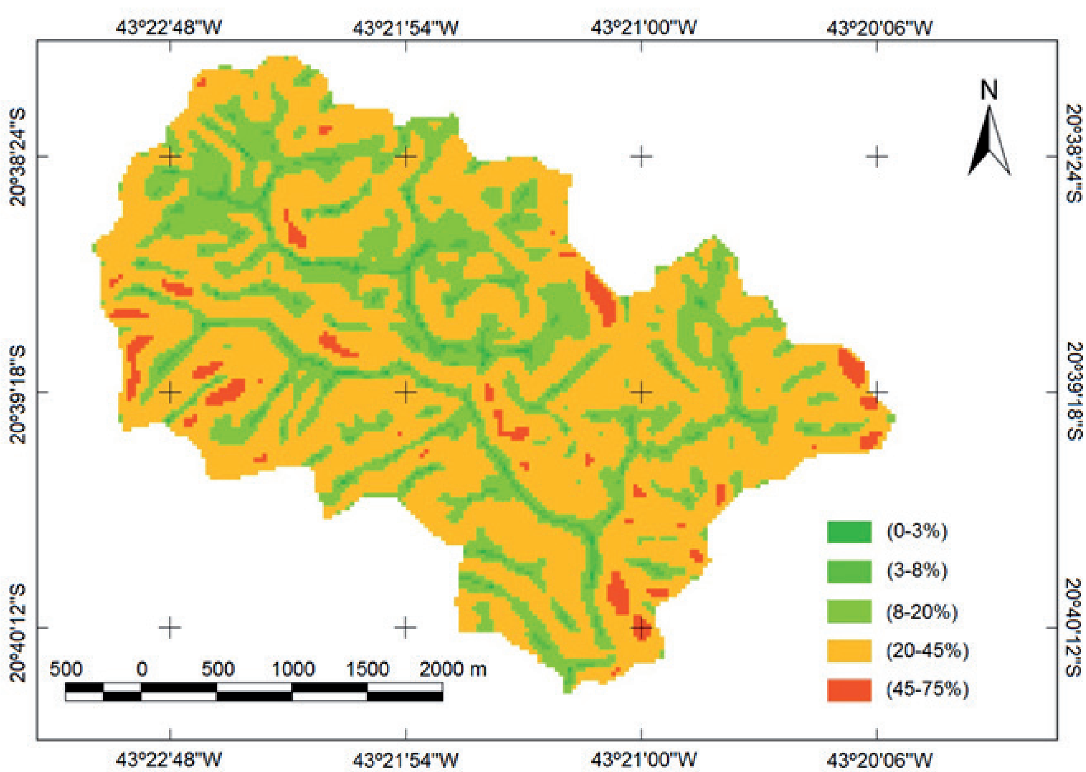
Table 1 presents the morphometric characterization of Mestre Campo Stream watershed, and Figure 3 graphically presents the natural geographic space.

Table 1 – Morphometric characterization and drainage network of Mestre Campo Stream watershed.

Morphometric characterization	
Contribution area (A)	13.930 km^2
Watershed perimeter (P)	23.560 km
Length of main axis (L)	5.278 km
Compactness coefficient (Kc)	1.781
Circularity index (Ic)	0.315
Form factor (F)	0.500
Elongation ratio (Re)	0.798
Drainage network characterization	
Length of drainage channels (ΣL)	28.634 km
Length of main water course (Cp)	6.869 km
Altimetric amplitude of main channel (H)	190.000 m
Drainage density (Dd)	2.056 km km^{-2}
Mean bifurcation ratio (Rb)	2.664
Basin order according to Strahler (1952) (O)	4ª
Mean declivity of main channel	2.766%

Source: Elaborated by the authors (2018).

Figure 3 – Mestre Campo Stream watershed.



Source: Elaborated by the authors (2018).

It was estimated an area of 13.93 km^2, perimeter of 23.56 km and length of the main axis of 5.28 km (TABLE 1), for the Mestre Campo Stream watershed, a natural space that can be characterized as elongated, since Kc (1.781), Ic (0.315), F (0.500), Re (0.798) and Rb (2.664) indices presented the same morphometric behavior. This result is confirmed when analyzing Figure 3, which shows the watershed geometry is far from a circular shape and it is more similar to the rectangular shape, which reflects the watershed elongated shape, characterized by the interpretation of the morphometric indices mentioned above.

Elongated watersheds tend to be conservative (SIQUEIRA et al., 2012), because there is a longer concentration time, and they are less susceptible to flooding under normal precipitation conditions (RODRIGUES et al., 2016).

In the study of Doce River watershed, in which Mestre Campo Stream is inserted, Marcuzzo et al. (2011) observed a geometry similar to a triangle. The result shows that the sub-watersheds may present different morphometry from the main watershed, as discussed by Bertolini and Cherem (2017), and that the physiographic characterization of sub-watersheds is necessary for better details of natural spaces and environmental management, respecting their aptitudes of land use.

The drainage system of Mestre Campo Stream watershed presents a dendritic configuration (FIGURE 3), fourth-order ramification (STRAHLER, 1957), drainage density of 2.056 km km^{-2} and an average bifurcation ratio of 2.66, considered by Villela and Mattos (1975) as being of medium capacity of drainage. This information reflects on the drainage capacity of a watershed, at which higher drainage density values are related to shorter drainage time and less risks of erosion, as discussed by Cardoso et al. (2006) and Zanata et al. (2011).

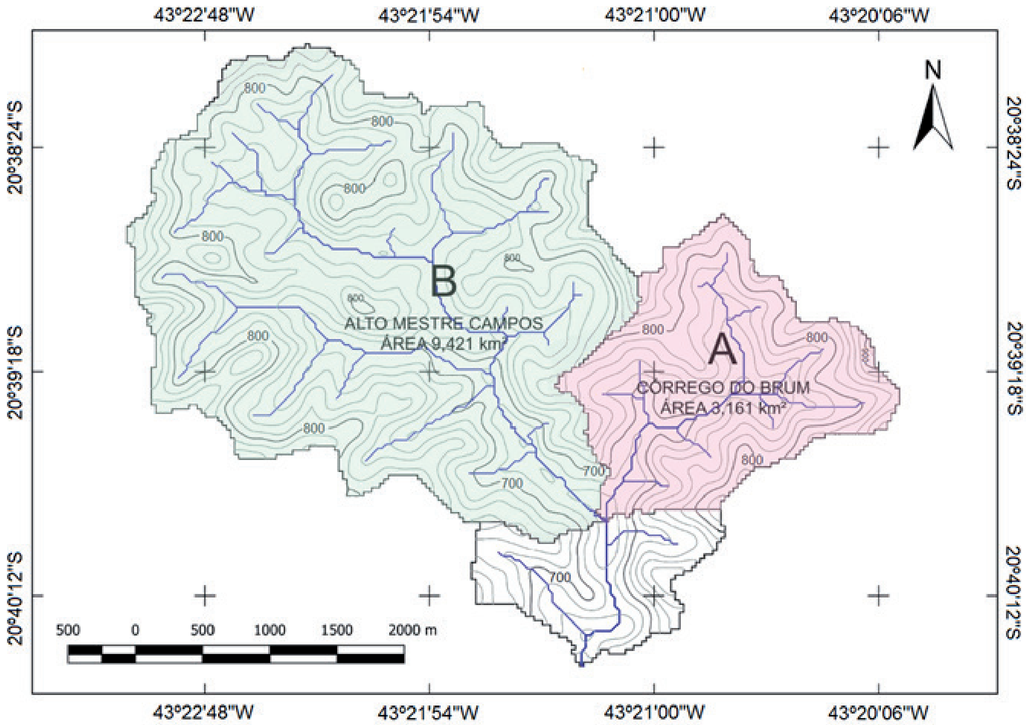
The federal watershed superior to the Mestre Campo Stream, Doce River watershed, presents greater branching of drainage network (tenth order), but lower value for the drainage density (0.03 km km^{-2}) and for the bifurcation ratio (2.16) (MARCUZZO et al., 2011). These values show that the sub-watershed has greater drainage capacity than the watershed in which it is inserted.

On the drainage of waters in Mestre Campo Stream watershed, the main water course has an altimetric amplitude of 190 meters distributed over 6,869 km of length, with an average slope of 2.77%. These values allow to estimate the average velocity of water runoff (0.818 m s^{-1} according to the NATURAL RESOURCES CONSERVATION SERVICE - NRCS, 2010) and the concentration time for the watershed (140 minutes according to NRCS, 2010), important variables when analyzing hydraulic systems, especially in projects of free ducts.

The concentration time depends, essentially, on the flow over the terrain, in which, the lower the flow velocity , the longer the concentration time for the watershed (MATA-LIMA et al., 2007); consequently, the lower the propensity for watershed flooding.

The average declivity observed for watershed slopes was 24.45%, corresponding to 61.79% of the studied area, allowing it to be classified as a watershed of highly undulating relief (EMBRAPA, 1979), as shown in Figure 4 and described in Table 2.

Figure 4 – Geomorphology of Mestre Campo Stream watershed.



Source: Elaborated by the authors (2018).

Table 2 – Distribution of slope classes of Mestre Campo Stream watershed.

Slope	Description	Area – km²	Percentage
0.0 % – 3.0 %	Plan	0.51275	3.75 %
3.1 % – 8.0 %	Smooth plan	0.51275	3.75 %
8.1 % – 20.0 %	Undulate	3.81521	27.93 %
20.1 % – 45.0 %	Highly undulate	8.43733	61.79%
45.1 % – 75.0 %	Mountainous	0.38355	2.81 %
> 75.0 %	Rugged	0.00000	0.00 %

Source: Elaborated by the authors (2018).

Figure 4 shows there is a softening of declivity when moving from the slopes to the main water course. Cardoso et al. (2006) and Rodrigues et al. (2016) emphasize the importance of relief in hydrological studies, such as the relationship between rainfall and runoff of watersheds in hydraulic studies, since they are important when estimating velocity in runoff surface, for example.

Since Mestre Campo Stream watershed presented a different shape from its upper watershed, also, the morphological description of these subunits is important in planning and managing an ecological unit, the sub-watersheds of Brum Stream and Alto Mestre Campo, which form Mestre Campo Stream, were also characterized according to their shapes and the results are presented in the next section.

Sub-watersheds Brum Stream and Alto Mestre Campo

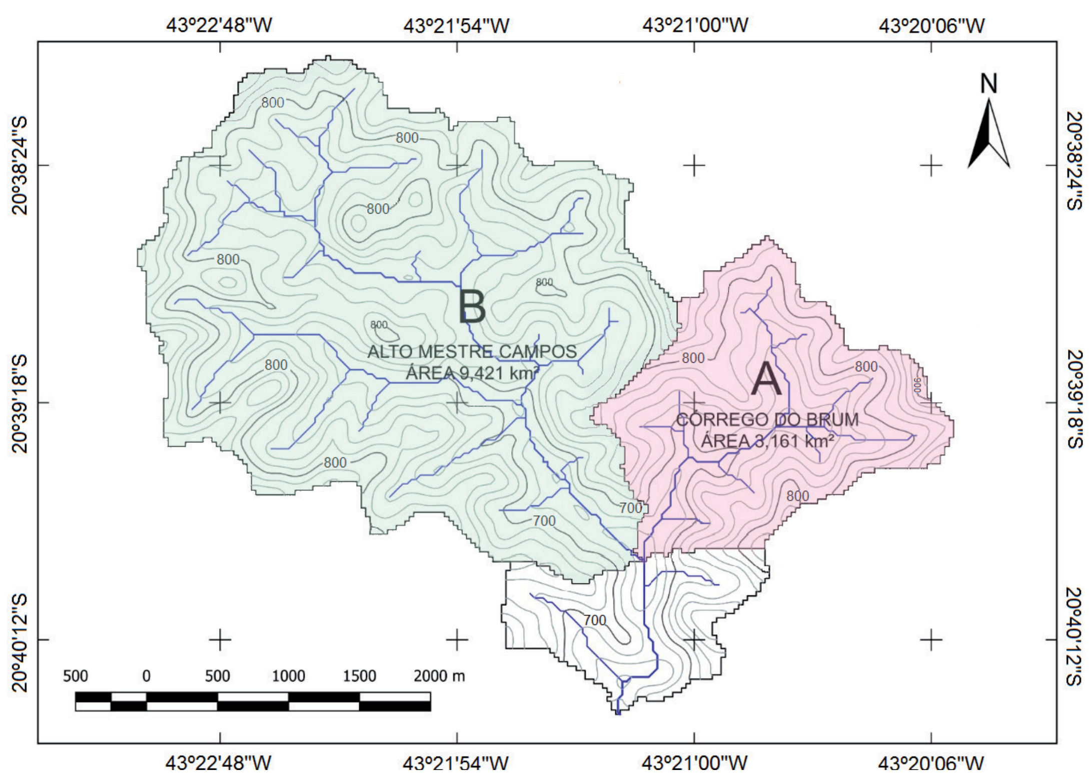
Table 3 presents the morphometric characterization of Brum Stream and Alto Mestre Campo sub-watersheds, and Figure 5 illustrates the geographical positions of these sub-areas.

Table 3 – Morphometric and drainage characterization of Brum Stream and Alto Mestre Campo watersheds.

-----	Brum Stream	Alto Mestre Campos
Morphometric characterization		
Contribution area (A)	3.161 km²	9.421 km²
Watershed perimeter (P)	10.200 km	17.380 km
Length of main axis (L)	2.458 km	4.420 km
Compactness coefficient (Kc)	1.618	1.597
Circularity index (Ic)	0.382	0.392
Form factor (F)	0.523	0.482
Elongation ratio (Re)	0.816	0.783
Drainage network characterization		
Length of drainage channels (ΣL)	6.780 km	19.160 km
Length of main water course (Cp)	2.742 km	5.393 km
Altimetric amplitude of main channel (H)	260.000 m	160.000 m
Drainage density (Dd)	2.145 km km^{-2}	2.034 km km^{-2}
Mean bifurcation ratio (Rb)	1.625	1.611
Basin order (O)	3ª	3ª
Mean declivity of main channel	9.48%	2.966%

Source: Elaborated by the authors (2018).

Figure 5 – Geographic position of Brum Stream (A) and Alto Mestre Campo (B) sub-watersheds.



Source: Elaborated by the authors (2018).

The Mestre Campo Stream watershed has its outlet on Piranga River, whose geographical latitude coordinates are of 20°40’31” South and longitude coordianates of 43°21’17” West, as illustrated in Figure 3. The sub-watersheds of Brum Stream and Alto Mestre Campo have different outlets, located under the geographic latitude coordinates of 20°39’55” South and longitude coordinates of 43°21’10” West, as illustrated in Figure 5. In addition, the sub-watershed Alto Mestre Campo has a contribution area (9.421 km^2) three times greater than that of Brum Stream (3.161 km^2).

The estimated values for Kc, Ic and F indicate oval and elongated shapes for sub-watersheds of Brum Stream and Alto Mestre Campo, respectively. As discussed for Mestre Campo Stream watershed, these results were expected, given the similarity of sub-watersheds geometries of circle and rectangle shapes, respectively.

Smaller values of elongation ratio (Re) are associated with elongated areas, and larger Re are associated with rounded areas. According to the classification of Aher et al. (2014), the sub-watershed of Brum Stream tends to be oval while the Alto Mestre Campo is characterized as elongated, corroborating what was mentioned above (TABLE 3).

These results show a heterogeneous morphometric behavior for Mestre Campo Stream watershed, in which the eastern section is more vulnerable to flooding than the western section. Given this scenario, it is necessary to adopt different environmental plans and managements for each space, respecting their variability and potential.

The drainage system found in both sub-watersheds has a dendritic conformation (FIGURE 5), showing a third order branch according to the classification proposed by Strahler (1957). The drainage density observed for the sub-watersheds of Brum Stream and Alto Mestre Campo were close, with values of 2.145 km km^{-2} and 2.034 km km^{-2}, respectively, being considered medians by Villela and Mattos (1975).

In addition, the main water course in sub-watershed of Brum Stream has an altimetric amplitude of 260 meters distributed in 2.742 km of extension, which generates an average slope of 9.48%, while for the sub-watershed of Alto Mestre Campo, the altimetric amplitude was 160 meters in 5.393 km of the main channel extension, presenting an average slope of 2.76%. These results are in line with those presented in Figure 4, at which it is possible to observe steeper areas in Brum Stream region when compared to Alto Mestre Campo.

According to the NRCS method (1972), these slope values configure an average runoff velocity of 1.514 m s^{-1} for the sub-watershed of Brum Stream and 0.846 m s^{-1} for Alto Mestre Campo. In addition, the estimated concentration time for the sub-watersheds of Brum Stream and Alto Mestre Campo are 30 minutes and 106 minutes, respectively. These results are consistent with all the discussion presented in this study and they are important for the hydraulic and the hydrological studies of the area.

Conclusion

The morphometric indices used for Mestre Campo Stream watershed characterization presented a natural space of elongated shape and a drainage network of fourth-order, dendritic configuration and medium capacity of water drainage.

The sub-watersheds that form the Mestre Campo Stream watershed presented heterogeneous physiographies, in which the Brum Stream presented oval shape and the Alto Mestre Campo sub-watershed elongated shape. The particularities of sub-watersheds reveal the need for different work plans and managements for Mestre Campo Stream watershed, in order to respect the potential and aptitudes of each space.

Caracterização morfométrica da bacia hidrográfica do Córrego Mestre Campo, no município de Piranga, Minas Gerais

Resumo

A múltipla dinâmica ambiental das bacias hidrográficas torna esses ambientes naturais interessantes objetos de estudos e, em áreas com poucas investigações científicas, tal como a bacia hidrográfica do Córrego Mestre Campo, a necessidade dessas investigações é ainda maior. Com a realização do presente trabalho, buscou-se caracterizar a morfometria da Bacia Hidrográfica do Córrego Mestre Campo, localizada no município mineiro de Piranga, como uma primeira atividade à criação de um plano de manejo aos recursos naturais disponíveis na área. Para isso, dados geomorfológicos TOPODATA foram utilizados em sistema de informação geográfica (SIG) para extração das informações morfométricas – área e respectivo perímetro, comprimento do eixo e da rede de drenagem – da área de estudo e, posteriormente, essas variáveis foram utilizadas na estimativa de indicadores físicos – fator de forma, índices de circularidade e de compacidade, razão de elongação e densidade de drenagem – para descrição da bacia hidrográfica. Os índices de forma indicaram comportamento alongado para a bacia, caracterizando-a como um espaço de baixa susceptibilidade a enchentes em condições normais de precipitação. Além disso, a rede de drenagem apresentou ramificação de quarta ordem e mediana capacidade de drenagem. As sub-bacias que compõem a Bacia Hidrográfica do Córrego Mestre Campo também foram caracterizadas e a Sub-bacia do Córrego do Brum apresentou forma arredondada, enquanto a Sub-bacia do Alto Mestre Campo mostrou características alongadas. Esses resultados ressaltam a heterogeneidade da Bacia Hidrográfica do Córrego Mestre Campo, que devem ser consideradas na elaboração de um plano para a gestão dos recursos hídricos da bacia hidrográfica estudada, respeitando as particularidades do espaço geográfico para uso racional dos recursos naturais.

Palavras-chave: Gestão ambiental. Índices de forma. SIG.

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