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MORPHOLOGY OF PARDO RIVER WATERSHED AT THE BORDER OF THE STATES OF BAHIA AND MINAS GERAIS

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ABSTRACT

The spatial analysis of watersheds, as well as the evaluation off the changes occurring in their catchment area along the time are essential for the qualification of environmental changes. This study aims to characterize morphometrically the Pardo river watershed, as well as to evaluate the changes in soil use and occupation occurring between 2001 and 2016. The morphometric analysis consisted of the determination of the geometric parameters, relief information and drainage network using Geographic Information Systems. The land use and occupation information was collected through data from the online mapping platform of the Brazilian Mapping and Land Use Mapping (MapBiomas). According to the results, morphometry indicated that the watershed has low propensity to flood occurrence and tendency to conservation; great part of its area is between 600 and 1000 m of altitude, with predominance of undulating and soft-undulating slopes. The analysis of land use and occupation showed that the area devoted to agricultural activities increased during the period evaluated and occupies most of the basin, while the area of forests was reduced, the second in size, and these two classes occupy more than 96 % of catchment area.

Palavras-chave:
Caracterização fisiográfica de bacias
Hidrologia
MapBiomas
SIG
Modelo digital de elevação hidrologicamente consistente (MDEHC)

MORFOLOGIA DA BACIA HIDROGRÁFICA DO RIO PARDO, DIVISA DOS ESTADOS DE MINAS GERAIS E DA BAHIA

RESUMO

A análise espacial de bacias hidrográficas, bem como o estudo das modificações ocorridas em sua área de captação são imprescindíveis para a avaliação de alterações ambientais. Este estudo objetiva caracterizar morfometricamente a bacia hidrográfica do rio Pardo, bem como avaliar as mudanças no uso e ocupação do solo ocorridas entre 2001 e 2016. A análise morfométrica consistiu na determinação dos parâmetros geométricos, de relevo e da rede de drenagem por meio dos Sistemas de Informações Geográficas. As informações de uso e ocupação do solo foram levantadas por meio de dados da plataforma online do Projeto de Mapeamento Anual da Cobertura e Uso do Solo do Brasil (MapBiomas). Como resultados, têm-se que a morfometria indicou que a bacia hidrográfica possui baixa propensão à ocorrência de enchentes e tendência à conservação; grande parte de sua área encontra-se entre 600 e 1000 m de altitude, com predominância de declividades onduladas e suave-onduladas. A análise de uso e ocupação do solo demonstrou que a área dedicada às atividades agropecuárias aumentou durante o período avaliado e ocupa a maior parte da bacia, enquanto a de florestas sofreu redução, sendo a segunda em tamanho, e estas duas classes ocupam mais de 96% da área de captação.

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INTRODUCTION

A watershed is defined as a topographically delimited area, defined as the catchment area, which is drained by an interconnected system of water courses, in such a way that the entire effluent flow is discharged at a single point known as an exutory (TUCCI, 2004), which constitutes the basic unit of environmental planning and management (BERNARDI *et al*., 2012).

One of the steps for good planning in hydrology is obtaining information such as shape, relief, distribution and number of channels in watersheds (DA SILVA PEIXOTO *et al.,* 2019). The mathematical study of these characteristics defines the morphometric analysis, in which it is possible to obtain indicators that relate to various processes within the catchment area, such as the form and the propensity to floods (ANDRADE *et al*., 2014; MOTTA *et al*., 2018), the drainage network and runoff and infiltration (FRAGA *et al*., 2014), and the relief and loss of soil by erosion (PEREIRA *et al*., 2015; SILVA *et al*., 2017). Several studies point out the importance of collecting morphometric information in watersheds (SANTOS *et al*., 2012; FELIPE *et al*., 2013; ABUD *et al*., 2015; LOPES *et al*., 2018; and SOUZA *et al*. 2018).

In the management of water resources, to understand the process of occupation and modification of hydrographic basins over time is as important as morphometry. The ratio of the proportion of areas such as: exposed soils, forests, urban and agricultural activities; directly impacts peak flow and runoff (MARQUES *et al*., 2016; AGUIAR, 2017) and sediment production (VANZELA *et al*., 2012).

Considering the consolidation of GIS (Geographic Information Systems), the morphometric characterization of hydrographic basins can be performed using an MDE (Digital Elevation Model), which is a digital model of the surface of a terrain created from elevation data captured by the satellite. According to Soares *et al*. (2011), a series of pre-treatments must first be performed to use the MDE in hydrological analyzes in order to make it a hydrographically consistent digital elevation model (MDEHC). This digital model must represent the relief in order to reproduce with accurately the flow path of water as seen in the real world.

The Pardo River watershed is one of the most important basins in northern Minas Gerais and southwestern Bahia. It is located between two states and has shared management; however, there is no river basin committee installed (BRASIL, 2017), which is an extremely important organ for the management of the basin. The importance of conducting morphometric and land use and occupation analyzes in this watershed comes from information on the occurrence of uncontrolled use of water resources and increased environmental degradation. This fact was already highlighted by Sampaio and Vargas (2011), who reported that several changes in land use and occupation over time are contributing to the pollution of rivers in the basin, caused mainly by pastoral and agricultural activities, irregular occupation and the dumping of domestic waste, both on the banks and inside the river itself.

Studies already performed in the watershed, such as the influence of consumptive uses of water on the flow of the main river (SANTOS, 2017), and the regionalization of flows for the Bahian part of the basin (DE CARVALHO, 2017), use morphometric data specific to the need for each study, with no information on land use and occupation. Therefore, the joint study of morphometry and land use and occupation for this basin is the differential of this study.

Thus, this study aims to morphometrically characterize the Pardo River watershed and evaluate the changes in land use and occupation that occurred between 2001 and 2016.

MATERIAL AND METHODS

The Pardo River is a federal basin, with its source at Montezuma, in Minas Gerais, and mouth at Canavieiras, in Bahia (Figure 1). Its catchment area includes a total of 32 municipalities, of which 19 are located in the state of Bahia and 13 in the state of Minas Gerais (SANTOS, 2017).

Average annual rainfall ranges from 703.72 mm, in the central region of the basin, to 1325.05 mm, closest to the mouth, with an average long-term annual rainfall of 886.25 mm. In a study performed by Santos (2017), it is reported that the average monthly flow for the Pardo River watershed ranged from 10.80 $m^3.s^{-1}$ (September) to

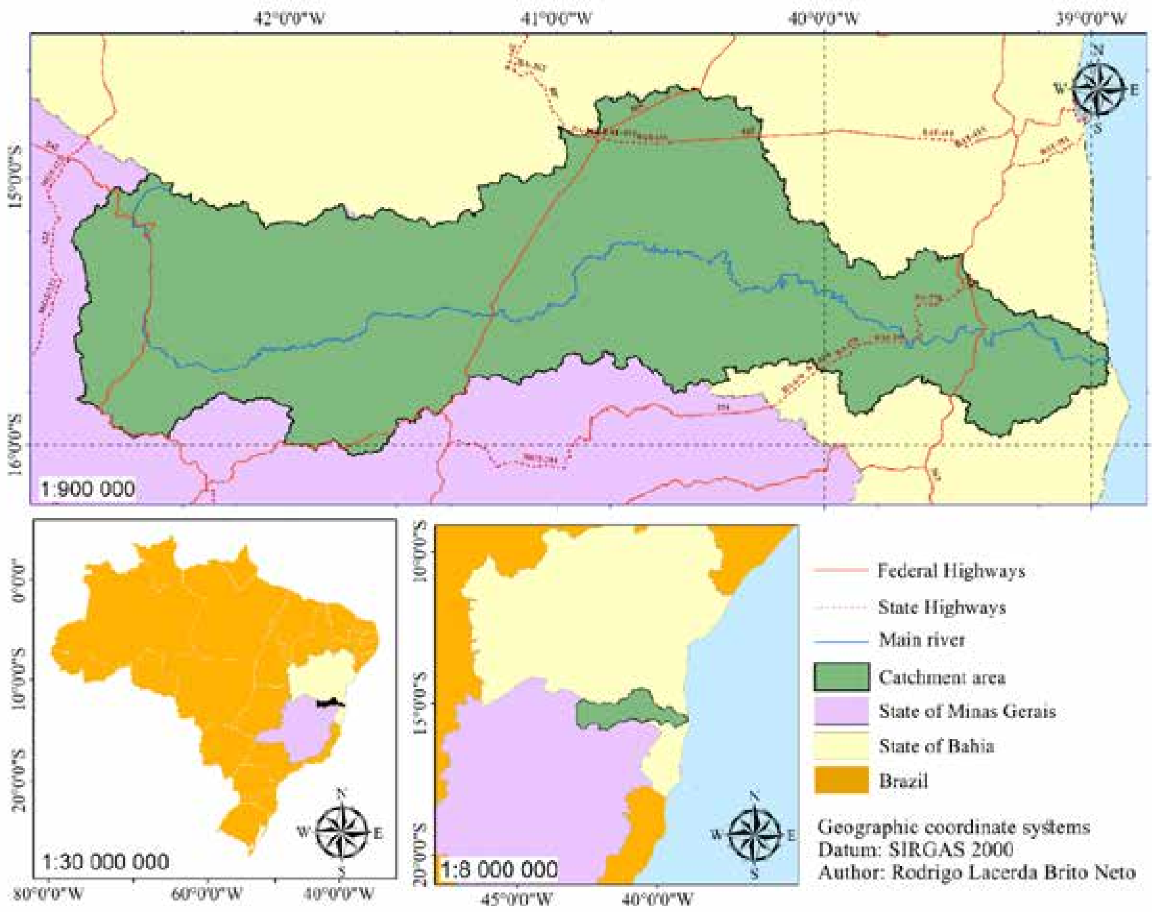

Figure 1. Geographic location of the Pardo River Watershed, Brazil

55.60 $m^3.s^{-1}$ (December), with the average annual flow being 22.90 $m^3.s^{-1}$. Furthermore, the months of November, December and January had the highest values of precipitation and flow.

The methodology described by Elesbon *et al*. (2011) was applied to generate the MDEHC, for which eight MDE cards were selected: 14S42_ZN, 14S405_ZN, 14S435ZN, 15S39_ZN, 15S42_ZN, 15S405_ZN, 15S435_ZN and 16S42_ZN through the images SRTM - Shuttle Radar Topography Mission - available for free on the TOPODATA project online platform, National Space Research Institute (INPE), with a spatial resolution of 30 m as recommended by Soares *et al*. (2011). The ESRI's ArcGIS® 10.2 software was used for manipulating SRTM images and obtaining the MDEHC.

The morphometric characteristics analyzed were grouped according to Tonello (2005), in geometric, relief and drainage characteristics; and the equations of the various parameters to estimate these characteristics were obtained by Villela and Mattos (1975), Tucci (2004), Tonello (2005) and Elesbon *et al*. (2011).

The geometric characteristics analyzed were: a) area (A), the entire drainage area included between the topographic dividers of a watershed projected in a horizontal plane; b) perimeter (P), length of the imaginary line along the watershed; c) axial length (L), greater length of the pelvis; d) form factor (Kf) (Equation 1), which relates the shape of the basin to that of a rectangle, corresponding to the ratio between the drainage area and the axial length of the basin; e) compactness coefficient (Kc) (Equation 2), that constitutes the relationship between the perimeter of the basin and the circumference of a circle of area equal to that of the basin; a minimum Kc equal to one unit would correspond to a circular basin and, for a elongated basin, its value is significantly higher than one; f) circularity index (Ic) (Equation 3): simultaneously with Kc, this index tends to unity as the basin approaches the circular shape and decreases as the shape becomes elongated.

$$Kf = \frac{A}{L^2} \quad (1)$$

$$Kc = 0.28 \times \frac{P}{\sqrt{A}} \quad (2)$$

$$Ic = \frac{(12.57 \times A)}{P^2} \quad (3)$$

where,
L = axial length, in km; and
P = total perimeter of the basin, in km; and
A = total area of the basin, in km².

The Kf, Kc and Ic indices can be divided into classes that divide a watershed into round, oval, oblong or long (VILLELA; MATTOS, 1975), as described in Table 1.

Considering the relief characteristics, the analyses performed were: a) slope, using the MDEHC classification according to EMBRAPA (2006), considering 0 to 3%, flat; 3 to 8%, smooth wavy; 8 to 20%, wavy; 20 to 45%, strong wavy; 45 to 75%, mountainous; and above 75%, a mountainous fort; the slope of the main river was also calculated using three different methods: S1, slope obtained based on the difference in level between the source and the mouth; S2, slope obtained based on the area equivalence criterion; and S3, constant equivalent slope obtained based on the speed of water displacement along the longitudinal profile of the watercourse; and b) altitude, obtained by directly extracting the values of each pixel from the MDEHC. The slope of the main river in the basin is extremely important in the runoff flow and, consequently, in the magnitude of the flood peaks (ALMEIDA *et al*., 2017).

Regarding the characteristics of the drainage network it was evaluated: a) hierarchy of the water courses, which consists of the classification of a given water course in the total set of the watershed in which it is located, allowing the ordering of all channels inserted in a catchment área; the methodology used for this purpose was proposed by Strahler (1952), in which the smallest channels without tributaries are considered to be of the first order; second order channels arise from the confluence of two first order channels and only receive first order tributaries; third-order channels arise from the confluence of two second-order channels, being able to receive affluents from channels of equal or lower orders, and so on; b) drainage density (Dd) (Equation 4), reflects the influence of geology, topography, soil and vegetation in the watershed. It is related to the time taken to drain the runoff from the basin.

$$Dd = \frac{Lr}{A} \quad (4)$$

where,
Lr = total length of rivers, in km; and
A = total area of the basin, em km².

França (1968) classified the drainage density as: low, medium, high and super high, according to Table 2.

Table 1. Values, formats and interpretation of the form factor (Kf), circularity index (Ic) and compactness coefficient (Kc)

Kf	Ic	Kc	Format	Environmental interpretation
1.00 a 0.75	1.00 a 0.80	1.00 a 1.25	Round	High tendency to flooding
0.76 a 0.50	0.81 a 0.60	1.26 a1.50	Oval	Median tendency to flooding
0.51 a 0.30	0.61 a 0.40	1.51 a 1.70	Oblong	Low tendency to flooding
< 0.30	< 0.40	> 1.70	Long	Conservation trend

Source: Villela; Mattos (1975)

Table 2. Values, classification and interpretation of drainage density results

Dd (km/km²)	Classification	Environmental interpretation
< 1.5	Low	Low surface runoff and increased infiltration
1.5 a 2.5	Mean	Median trend of surface runoff
2.5 a 3.0	High	High tendency to surface runoff and flood
> 3.0	Super high	High tendency to surface runoff, flood and erosion

Source: França (1968)

With regard the drainage network, the sinuosity index (Is) (Equation 5) was also evaluated, which is the relationship between the distance from the exutory of the main river and the most distant source measured in a straight line (Lt), and the length of main channel (Lp). Sinuosity can be classified according to Is in: very straight (Is <20%), straight (20% to 29%), rambling (30% to 39%), sinuous (40% to 49%) and very sinuous (Is ≥ 50%) (ROMERO *et al.*, 2017).

$$Is = \frac{100(Lp-Lt)}{Lp} \quad (5)$$

where,
Lp = length of the main river, in km; and
Lt = length of thalweg, in km.

The coverage and land use classifications of the MapBiomas collection are based on mosaics of Landsat images. Each mosaic is produced by the spatial integration of the different Landsat scenes present in each card and by the temporal integration pixel by pixel, by calculating the median, from the set of scenes available for a given time interval. These time intervals were defined according to the variation in the phenology of plant types in each of the Brazilian biomes, as a strategy to improve the classification results (MAPBIOMAS, 2017).

Through the online platform, it is possible to download data at the biome level on a scale of 1: 1,000,000 in the GeoTiff format, as well as verify the quality of the data. All mosaics of each year are classified as low, medium and high quality, according to the interferences (cloud, fog, cloud shadow, etc.) in the Landsat scenes. Regarding the quality of the classification, it is possible to observe for each biome the information of global accuracy (it is the estimate of the proportion of the global correctness of the classifiers), area discrepancy (fraction of the error attributed to the amount of area incorrectly assigned to the classes by mapping) and allocation disagreement (proportion of displacement errors). The values of the quality of the classification vary according to the level of detail of the classes of land use and occupation. These classes are divided into three levels, with level 1 being less detailed (less classes) and with higher global accuracy values, and level 3 being the more detailed (more classes) and with lower global accuracy values. When selecting level 1, there is more reliable data, but with a lower level of detail of classes. Levels and classes can be checked in Mapbiomas (2017). This is a recent initiative, but some studies are already using MapBiomas as a data source (ROSA, 2016; SOUSA, 2017; RODRIGUES, 2018; MARIANO *et al.*, 2018).

The years for the analysis of temporal change in land use and occupation were chosen in this work, observing the following aspects: a minimum interval of ten years between them, quality of the mosaics that overlap the drainage area of the basin with medium to high quality and with the best global accuracy values. Thus, for the years 2001 and 2016, land use and occupation maps for the biomes that are inserted in the catchment area of the basin (Atlantic Forest, Cerrado and Caatinga) to level 1 were downloaded.

The biome maps were inserted in the ArcMap 10.2 program, where they were joined, redesigned for UTM and SIRGAS 2000 *datum* and cut out to the basin format, considering morphometric information obtained, such as area and perimeter. All classes of level 2 or 3 were reclassified to level 1, as this is the level where an accuracy was observed within the previously established level. Thus, the level 1 classes were defined as: Forest, Natural non-forest formations, Agriculture, Areas without vegetation and water. Each class had its area calculated and compared, in order to assess whether changes have occurred.

RESULTS AND DISCUSSION

The morphometric parameters obtained in this study for the Pardo river watershed, is shown, in summary, in Table 3.

The drainage area obtained for the study region was 32650 km², with its perimeter having a total length of 2154 km. The Kf, Kc and Ic values obtained were 0.185, 3.338 and 0.088, respectively. As these values are distanced from the unit, it

Table 3. Morphometric parameters of the Pardo river watershed

Morphometric parameters			Value
Geometric	Area (km²)		32650
	Axial length of drainage area (km)		420
	Perimeter (km)		2154
	Form factor – Kf		0.185
	Compactness index – Kc		3.338
	Roundness index – Ic		0.088
Drainage Network	Total length of the drainage network (km)		14335
	Main river length (km)		807
	Thalweg length (km)		383
	Sinuosity index (%)		5.55
	Total channels		5312
	Channel Length (km)	1st Order	6649
		2nd Order	3220
		3rd Order	1686
		4th Order	883
		5th Order	263
		6th Order	564
	Drainage density – Dd (km/km²)		0.44
	Hydrographic density – Dh (channels/km²)		0.16
Relief	Maximum Altitude (m)		1767
	Minimum Altitude (m)		1
	Mean Altitude (m)		669.62
	Median Altitude (m)		810
	Altimetric amplitude (m)		1766
	Declivity (m/km)	S1	1.32
		S2	1.08
		S3	0.90

can be inferred that the basin has a tendency to conservation according to the classification of Villela and Mattos (1975).

It is important to highlight that, even though the Kf, Kc and Ic coefficients express a trend through geometric relationships, the fragility of the basin in terms of its susceptibility to flooding does not depend only on these factors (GARCEZ; ALVAREZ, 1988). This statement can be exemplified by relating the studies performed in the Itajaí-SC River watershed, which indicate that the regions of the middle and upper valley of the Itajaí River have had frequent occurrences of flooding during the last ten years (SANTOS *et al.*, 2014; FRAGA, 2015; SILVA; SOUZA, 2016). However, the analysis by Gerber *et al*. (2018) showed values of 1.51 for Kc and 0.43 for Kf for the same basin, which indicate a low propensity to flooding.

The sum of the lengths of all channels totaled 14,335 km, of which, 807 km belong to the largest extension of the main river (Rio Pardo), which has a 383 km thalweg. With its source in Montezuma-MG and mouth in Canavieiras-BA, the main channel has a sinuosity index of 52.5%, being classified as very sinuous, presenting channels of up to 6th order, thus being highly branched. Nardini *et al*. (2013) and Moreli *et al*. (2014) reported that a high sinuosity favors less sediment transport and, consequently, less chances of silting in favorable conditions.

The value found for the drainage density was 0.44 km / km², with 0.16 channels / km². Thus, the Pardo river watershed is characterized as having a low drainage capacity. According to Villela and Mattos (1975), drainage density can vary from 0.5 km/km², in basins with poor drainage, to 3.5 km / km² or more in well-drained basins. A low Dd value also indicates the potentiation of groundwater infiltration, expanding groundwater recharge and reducing the effects of peak flows, reducing the risk of leakage from river channels (FRAGA *et al*., 2014).

The results of the altimetry analysis revealed that the average altitude was 669.62 m, with a minimum of 1 m and a maximum of 1767 m. The analysis of the hypsometric curve showed that the median altitude was 810 m and that 0.49% of the Pardo river watershed area is above 1150 m, as well as 63% of the area is between 600 and 1000 m altitude (Figure 2).

The analysis of the slope of the basin revealed that 34.41% of the area has relief in the soft-wavy class, 29.48% in the wavy class, 18.04% has soft relief, 15.78% as being strong-wavy, 2.23% in the mountainous class and 0.06% with strong-mountainous relief (Figure 3).

According to Felipe *et al*. (2013), knowing the relief in the actions of planning and management of watersheds is of fundamental importance. Rodrigues *et al*. (2011) reported that, in areas of greater declivity and unprotected vegetation, the possibilities of degradation of the watershed increase. This information is confirmed by Pereira *et al*. (2015) and Silva *et al*. (2017) who, when quantifying soil loss by laminar erosion in different watersheds, identified that the most critical areas of soil loss are associated with high declivity.

Na Figura 4 estão apresentados o perfil longitudinal do rio principal e as declividades S1, S2 e S3, para as quais foram obtidos os valores de 1,32 m/km (0,13%), 1,076 m/km (0,11%) e 0,898 m/km (0,09%) respectivamente. Segundo Elesbon *et al*. (2011), o modelo S3 é aquele que melhor representa a declividade do rio, porque leva em consideração o tempo de percurso da água ao longo da extensão do perfil longitudinal.

In Figure 4 is presented the longitudinal profile of the main river and the slopes S1, S2 and S3, for which the values of 1.32 m/km (0.13%), 1.076 m/km (0.11%) and 0.898 m/km (0.09%) were obtained, respectively. According to Elesbon *et al*. (2011), the S3 model is the one that best represents the slope of the river, because it takes into account the water travel time along the length of the longitudinal profile.

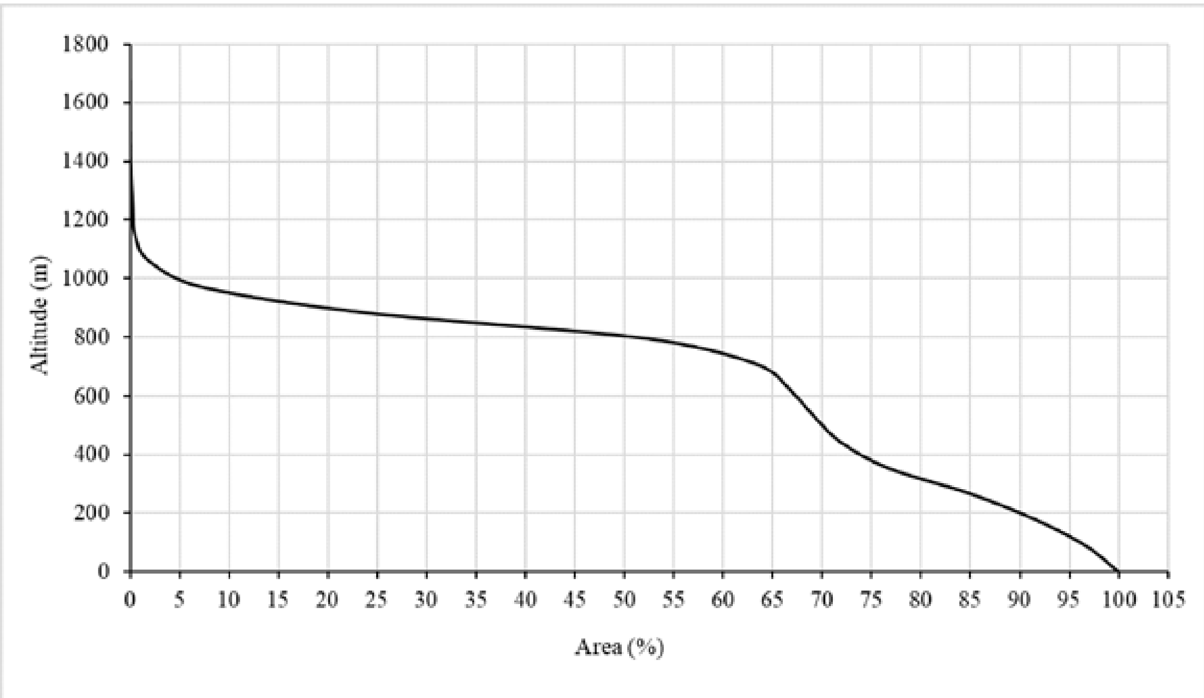

Figure 2. Hypsometric curve of the Pardo river watershed, Brazil

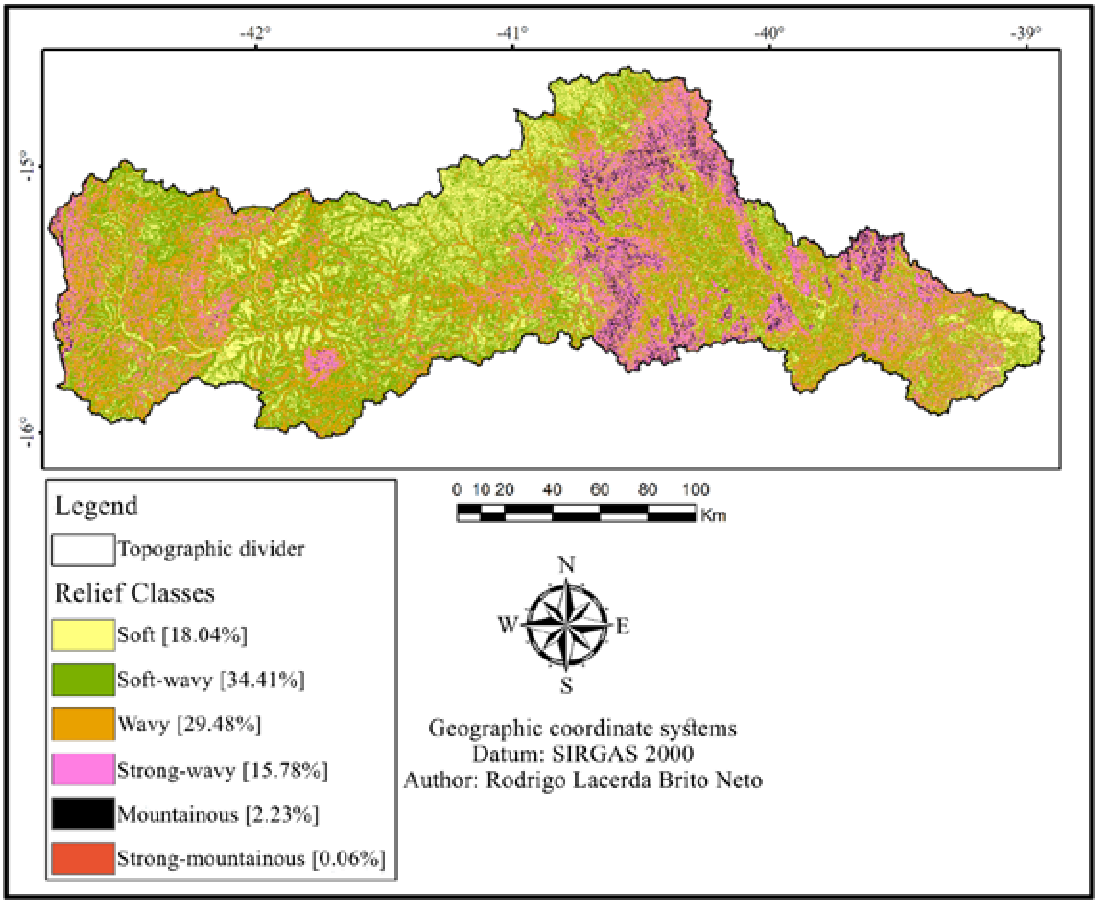

Figure 3. Slope of the Pardo River watershed, Brazil

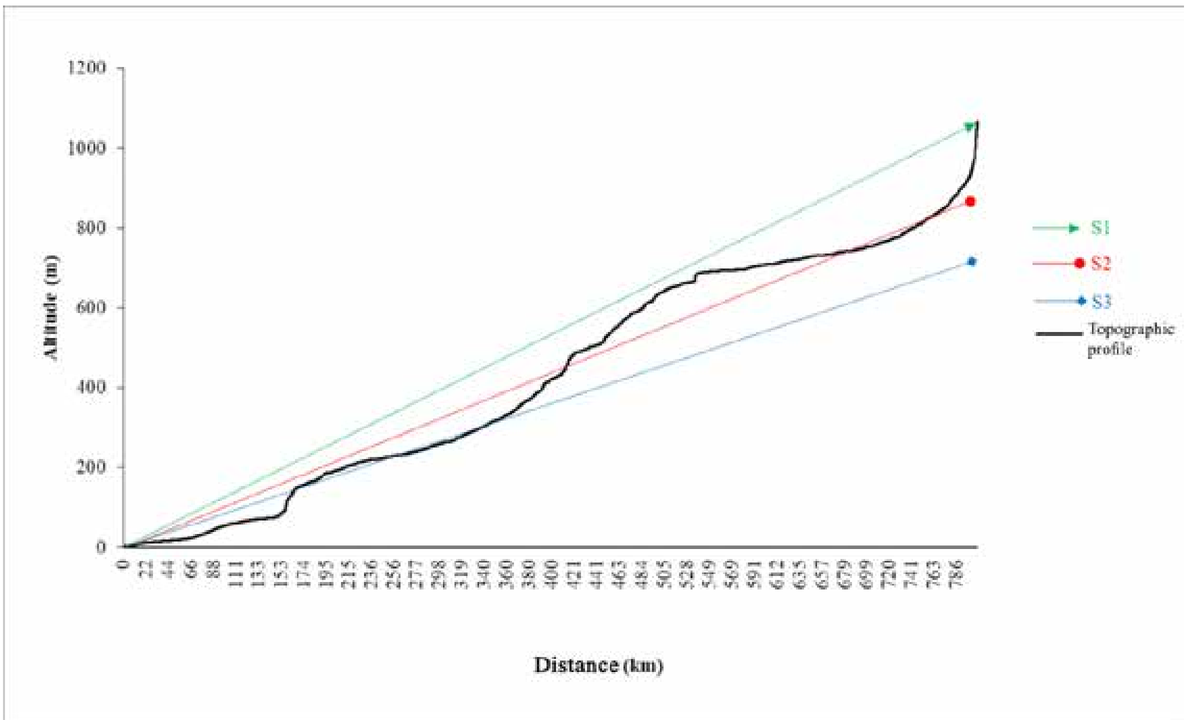

Figure 4. Longitudinal profile of the main river and slopes using the S1, S2 and S3 methods, in the Pardo river watershed, Brazil

Considering the morphometric aspects related to the study of floods in the Sapucaí-MG river watershed, Almeida *et al*. (2017) found the value of 0.01% for the S3 slope in the main river stretch, reporting that flood events are frequent in cities close to the stretch where the flow of the river is slower. The value found for the S3 slope in this study was also considered low, however the drainage shape and density characteristics of the Pardo-BA river watershed differ from that of the Sapucaí-MG river watershed. The Sapucaí-MG river watershed is more oval and with a higher Dd value, which may explain the floods reported by the authors.

The soil coverage of the Pardo River watershed has changed over the years, with the agricultural and forest class being the ones that showed the greatest change between the periods analyzed (Figure 5). From 2001 to 2016 there was an increase of 4.06% in the area destined for agriculture and a reduction of 5.04% in the forest area. With minor changes, the classes of non-forest natural formations, areas without vegetation and water suffered increases of 0.49%, 0.45% and 0.04%, respectively.

The relationship between the proportion of areas without vegetation (exposed and urban soil) with areas with vegetation cover (arboreal and non-arboreal) within a watershed influences surface runoff, which consequently leads to responses in erosion, production and sediment transport.

In relation to the seasonal dynamics of agricultural land cover and its effect on the generation of surface runoff in the basin drained by the high valley of the Marrecas River-PR, Aguiar (2017) concluded that there was a strong correlation between the increase in peak flows and the occupation by exposed soil, peaks ranging from 0.78 to 1.64 $m^3.s^{-1}$, per km^2 of exposed soil. Responses to land use and occupation in sediment production were verified by Vanzela *et al*. (2012), reporting that the use and occupation of soils significantly influenced the concentration of total and dissolved solids in the dry period, as well as the electrical conductivity and the specific flow in the dry and wet periods, with anthropized areas as the major contributors in the production of sediments in the two hydrographic basins of the study. Likewise, Cabral and Reis (2015) reported that areas such as urbanization and exposed soils were the ones that produced the most sediment

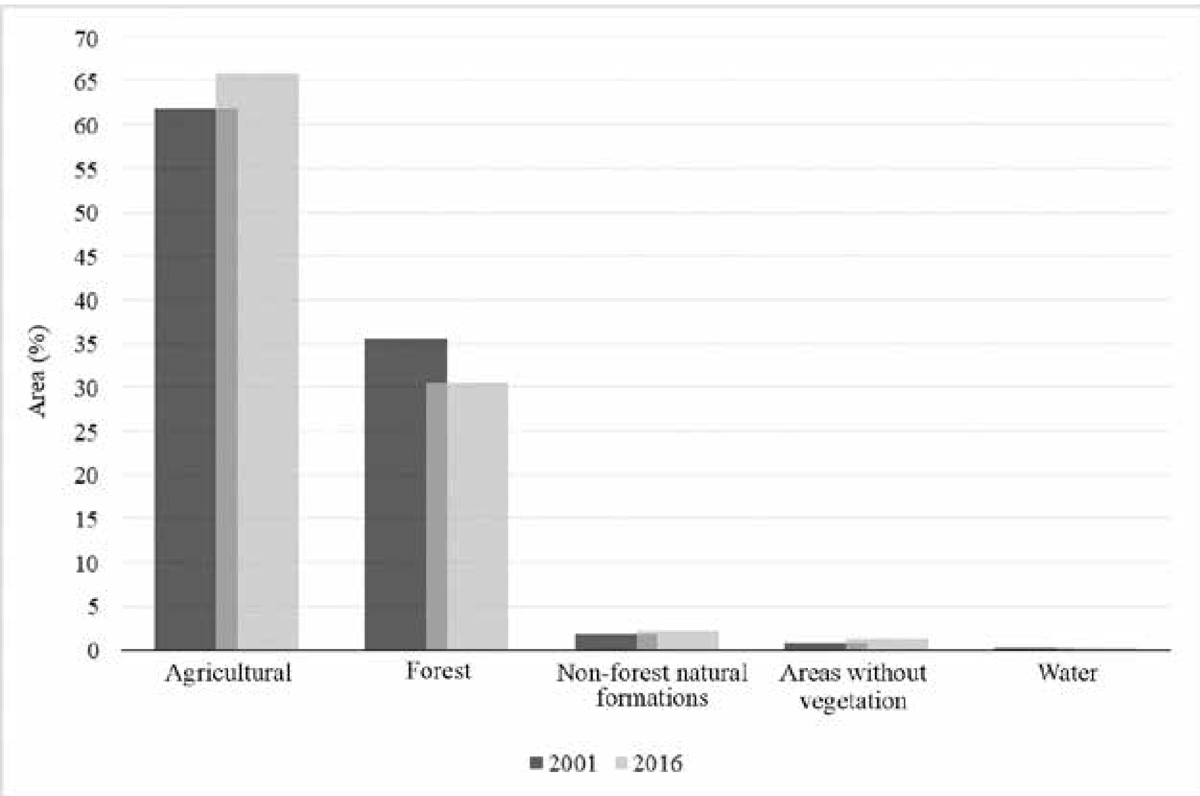

Figure 5. Land use and occupation for the years 2001 and 2016 in the Pardo River watershed, Brazil

during 2010, in the Jacarecica-AL river watershed.

An alternative that reduces the surface runoff and, consequently, the deposit of sediments in water courses is the increase of forested areas. Marques *et al*. (2016) concluded that, despite the 80.9% increase in the urbanization area in the Córrego do Luciano-SP sub-basin, there was a reduction in the direct surface runoff due to the reduction of the exposed soil areas by approximately 78.3%. This reduction is due to the addition of arboreal vegetation areas, which offset the effect of urban expansion on the region's hydrological regime.

In this study, the areas of forest and without vegetation, in 2016, occupied, respectively, 30.5% and 1.2% of the total, which may indicate that the Pardo River watershed has a low sediment production and a possible low surface runoff. However, it is important to note that 65.88% of the basin is occupied by agricultural activities and, depending on the management practices adopted, may affect the surface runoff and the sediment input in basins (ZHANG *et al*., 2004).

Watershed morphometric information can serve as input data in hydrological models. (PONTES, 2015). These data can help to prevent and defend against critical hydrological events of natural origin or resulting from the inappropriate use of natural resources, which is one of the objectives of the National Policy of Water Resources (PNRH) (BRASIL, 1997); as well as the articulation of the management of land use with that of water resources (BRASIL, 1997) is a general guideline of the PNRH.

CONCLUSION

- The Pardo River watershed is a large and long basin, whose shape favors conservation. It has a drainage network with channels of up to sixth order and low drainage density with a very winding main river. Most of its area is between 600 m and 1000 m, with an altimetric amplitude grid. These characteristics indicate that the basin under study has low surface runoff, facilitating the infiltration and storage of water.
- The area dedicated to agricultural activities increased during the evaluated period and occupies most of the basin, while the flowering area was reduced, the second largest in size. The two classes occupy more than 96% of the watershed and are the areas occupied by classes of non-vegetated areas, natural non-forest vegetation and water. These data demonstrate the importance of constant monitoring of land use and land cover for soil conservation and of the water in the basin. Therefore, it is recommended to study where these losses of forest areas may occur, assessing, for example, the situation of permanent preservation areas.
- Morphometric analysis, together with information on land use and coverage, showed to be complementary and are indispensable for the management of water resources.

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REFERENCES

ABUD, E.A.; LANI, J.L.; ARAÚJO, E.A.; AMARAL, E.F.; BARDALES, N.G.; FERNANDES FILHO, E.I. Caracterização morfométrica das sub-bacias no município de Xapuri: subsídios à gestão territorial na Amazônia Ocidental. **Revista Ambiente e Água**, v.10, n.2, p. 431-441, 2015.

AGUIAR, W.de. **Simulações hidrológicas de cenários de uso e ocupação do solo na bacia drenada pelo alto vale do rio Marrecas – PR**. 108f. Tese (Doutorado em Engenharia Agrícola) – Universidade Estadual do Oeste do Paraná, Paraná, 2017.

ALMEIDA, L.T.; ABREU, M.C.; FRAGA, M.S.; SILVA, D.D.; CECÍLIO, R.A. Aspectos morfométricos relacionados ao estudo de enchentes na bacia do rio Sapucaí, Minas Gerais. **Nativa**, v. 5, n. 3, 2017.

ANDRADE, S.L.; FERREIRA, V.O.; SILVA, M.M. Elaboração de um mapa de risco de inundações da bacia hidrográfica do córrego São Pedro, área urbana de Uberlândia-MG. **Caderno de Geografia**, v.24, n.41, p.1-16, 2014.

BERNARDI, E.C.S.; PANZIERA, A.G.; BURIOL, G.A.; SWAROWSKY, A. Bacia hidrográfica como unidade de gestão ambiental. **Revista Disciplinarum Scientia (Naturais e Tecnológicas)**, Santa Maria, RS, v.13, n.2, p. 159-168, 2012.

BRASIL. Agência Nacional de Águas. Ministério do Meio Ambiente (Org.). Conjuntura dos recursos hídricos no Brasil**:** informe 2017. Brasília: ANA, 2017. 215 p. Disponível em: <http://conjuntura.ana.gov.br/conjuntura>. Acesso em: 21 jun. 2018.

BRASIL. Lei nº 9.433, de 8 de janeiro de 1997. **Institui a Política Nacional de Recursos Hídricos, cria o Sistema Nacional de Gerenciamento de Recursos Hídricos, regulamenta o inciso XIX do art. 21 da Constituição Federal, e altera o art. 1º da Lei nº 8.001, de 13 de março de 1990, que modificou a Lei nº 7.990, de 28 de dezembro de 1989**, Brasília, DF, 1997. Disponível em: http://www.planalto.gov.br/ccivil_03/LEIS/L9433.htm. Acesso em: 30 de maio de 2020.

CABRAL, S.L.; REIS, R.S. Influência do uso e ocupação do solo na produção de sedimentos na bacia do rio Jacarecica. **Revista de Geografia**, v. 32, n. 2, p. 147-157, 2015.

DA SILVA PEIXOTO, F.; RODRIGUES, J.B.; DE MELO ALBUQUERQUE, P.I.. Gestão integrada dos recursos hídricos e a problemática das inundações urbanas. **Geografia**, v. 28, n. 1, p. 187-206, 2019.

DE CARVALHO, S.R. **Regionalização de Vazões Para a Parte Baiana da Bacia Hidrográfica do Rio Pardo**. 80 f. Dissertação (Mestrado em Ciências Ambientais) – Universidade Estadual do Sudoeste da Bahia, Itapetinga, 2017.

ELESBON, A.A.A.; GUEDES, H.A.S.; DA SILVA, D.D.; e DE CASTRO, I. Uso de dados SRTM e plataforma SIG na caracterização morfométrica da bacia hidrográfica do Braço Norte do Rio São Mateus-Brasil. **Revista Escola de Minas**, v.64, n.3, p. 281-288, 2011.

EMBRAPA. Centro Nacional de Pesquisa de Solos (Rio de Janeiro, RJ). Sistema brasileiro de classificação de solos. 2. ed. Rio de Janeiro: EMBRAPA-SPI, 2006.

FELIPE, A.C.; CAMPOS, S.; PARIZOTO, N.M.S.F.; NARDINI, R.C.; TRAFICANTE, D.P. Geoprocessing applied in morphometric of the Ribeirão do Veado watershed – Piratininga (SP), seeking the conservation of the water resources. **Brazilian Journal of Applied Technology for Agricultural Science**, v.6, n.2, p. 89-95, 2013.

FRAGA, M.S.; FERREIRA, R.G.; SILVA, F.B.; VIEIRA, N.P.A.; SILVA, D.P.; BARROS, F.M.; MARTINS, I.S.B. Caracterização morfométrica da bacia hidrográfica do rio Catolé Grande, Bahia, Brasil. **Nativa**, v.2, n.4, p. 214-218, 2014.

FRAGA, N.C. Clima, gestão do território e enchentes no Vale do Itajaí-SC. **Terra Livre**, v.1, n.20, p. 159-170, 2015.

FRANÇA, G. V.de. **Interpretação fotográfica de bacias e de redes de drenagem aplicada a solos da região de Piracicaba**. 151f. Tese (Doutorado em Agronomia/Solos e Nutrição de Plantas) – Escola Superior de Agricultura "Luiz de Queiroz", Universidade de São Paulo, Piracicaba, 1968.

GARCEZ, L.N; ALVAREZ, G.A**.** Hidrologia. 2. ed. São Paulo: Editora Edgard Blucher, 1988.

GERBER, D.; PERTILLE, C.T.; VIEIRA, F.S.; CORRÊA, B.J.S.; e DE SOUZA, C.F. Caracterização morfométrica da bacia hidrográfica do Rio Itajaí–Santa Catarina**. Acta Biológica Catarinense**, v.5, n.1, p. 72-83, 2018.

LOPES, E.R.do N.; DE SOUZA, J.C.; DE SOUSA, J.A.P.; ALBUQUERQUE FILHO, J.L.; e LOURENÇO, R.W. Modelagem ambiental de bacias hidrográficas: caracterização morfométrica e pedológica da bacia do rio Una–Ibiúna, Brasil. **Geosul**, v.33, n.66, p. 105-127, 2018.

MAPBIOMAS. Algorithm Theoretical Base Document e Results – MapBiomas General "Handbook". [S.l.]: [s.n.], 2017. Disponível em: <mapbiomas.org/pages/methodology> Acesso em: 21 jun. 2018.

MARIANO, D.A.; SANTOS, C.A.C.dos; WARDLOW, B.D.; ANDERSON, M.C.; SCHILTMEYER, A.V.; TADESSE, T.; SVOBODA, M.D. Use of remote sensing indicators to assess effects of drought and human-induced land degradation on ecosystem health in Northeastern Brazil. **Remote Sensing of Environment**, [S.l.], v. 213, p. 129-143, 2018.

MARQUES, S; M.; VICENTE, G.Z.; LIMA, C.G.da R. Estudo da Cobertura Vegetal e Modelo Chuva x Vazão na Sub-Bacia do Córrego do Luciano Município de Jardinópolis-SP. **Revista Científica ANAP Brasil**, v.9, n.17, p. 59-73, 2016.

MORELI, A.P.; PEREIRA, D.P.; DA SILVA, S.F. Caracterização morfométrica da sub-bacia hidrográfica do córrego Cancã, município de Venda Nova do Imigrante-ES, Brasil. **Nucleus**, v.11, n.2, p. 385-395, 2014.

MOTTA, P.N.S.D.; GLOAGUEN, T.V.; SANTOS, M.S.T.; DA SILVA FERREIRA, A.T.; e MOTTA, T.O. Análise Morfométrica da bacia hidrográfica Do Rio Subaé, Bahia. **Ambiência**, v.13, n.2, p. 470-485, 2018.

NARDINI, R.C.; POLLO, R.A.; CAMPOS, S.; DE BARROS, Z.X.; CARDOSO, L.G.; e GOMES, L.N. Análise morfométrica e simulação das áreas de preservação permanente de uma microbacia hidrográfica. **Irriga**, v.18, n.4, p. 687-699, 2013.

PEREIRA, T.S.R.; SANTOS, K.A.; SILVA, B.F.; FORMIGA, K.T.M. Determinação e Espacialização da Perda de Solo da bacia hidrográfica do Córrego Cascavel, Goiás**. Revista Geográfica Acadêmica**, v.9, n.2, p. 76-93, 2015.

PONTES, P. R.; COLLISCHONN, W.; FAN, F. M.; PAIVA, R. C.; BUARQUE, D. C. Modelagem hidrológica e hidráulica de grande escala com propagação inercial de vazões. **Revista Brasileira de Recursos Hídricos**, v. 504 20, n. 4, p. 888-904, 2015.

RODRIGUES, S.B. **Espécies semeadas e colonizadoras garantem a trajetória sucessional da restauração de florestas na bacia do Alto Xingu**. 48f. Dissertação (Mestrado em Ecologia) – Universidade de Brasília, Brasília, 2018.

RODRIGUES, V.A.; FENNER, P.T.; AMARAL, L.P.; BENTEL, C.A.; IMANA, J.; BLANCO, O.E. Degradação ambiental da microbacia do Ribeirão Tamanduá em relação com sua morfometria. **Revista Forestal Venezolana**, v.55, n.1, p. 23-28, 2011.

ROMERO, V.; MARTINS F.K.T.; NORONHA, M.F.F. Estudo hidromorfológico de bacia hidrográfica urbana em Goiânia/GO. **Ciência e Natura**, v.39, n.2, 2017.

ROSA, M.R. Comparação e análise de diferentes metodologias de mapeamento da cobertura florestal da mata atlântica. **Boletim Paulista de Geografia**, v. 95, n.95, p. 25-34, 2016.

SAMPAIO, N.; VARGAS, M.A.M. As paisagens do rio Pardo desvendada pela comunidade Ribeirinha no Sudoeste da Bahia: Conversações entre o percebido e o vivido. **Ateliê Geográfico**, v.4, n.4, p. 147-177, 2011.

SANTOS, A. M.; TARGA, M. S.; BATISTA, G. T.; DIAS, N. W. Análise morfométrica das sub-bacias hidrográficas Perdizes e Fojo no município de Campos do Jordão, SP, Brasil. **Revista Ambiente e Água**, v.7, n.3, p. 195-211, 2012.

SANTOS, L.C.O. **Influência dos usos consuntivos da água e do uso e cobertura da terra na vazão da bacia hidrográfica do rio Pardo**. 80f. Dissertação (Mestrado em Ciências Florestais) – Universidade Estadual do Sudoeste da Bahia, Vitória da Conquista, 2017.

SANTOS, C.F. DOS; TORNQUIST, C.S.; MARIMON, M.P.C. Indústria das enchentes: impasses e desafios dos desastres socioambientais no vale do Itajaí. **Geosul**, v.29, n.57, p. 197-216, 2014.

SILVA, E.E.R.; LOPES, E.S.; DE SOUSA, L.R.P.; MACEDO, M.A.; DE CASTRO BOLINA, C.; GOMES, M.I.L. Estimativa da erosão laminar na bacia hidrográfica do Ribeirão João Leite–GO a partir de análise espacial de dados. **Revista Estudo e Debate**, v.24, n.3, 2017.

SILVA, P.R. da; SOUZA, F.de. Inundações no município de Rio do Sul: uma análise dos eventos de 2011 e 2013 à luz da gestão de risco de desastres. **Revista Ordem Pública**, v.9, n.1, p.163-179, 2016.

SOARES, V.P.; MOREIRA, A.D.A.; ALVARES SOARES RIBEIRO, C.A.; GLERIANI, J.M.; GRIPP JUNIOR, J. Mapeamento de áreas de preservação permanentes e identificação dos conflitos legais de uso da terra na bacia hidrográfica do ribeirão São Bartolomeu-MG. **Revista Árvore**, v.35, n.3, 2011.

SOUSA, S.B. **Dinâmica territorial e padrões espaciais da pecuária brasileira**. 182f. Tese (Doutorado em Geografia) – Universidade Federal de Goiás, Goiânia, 2017.

SOUZA, C.F.; PERTILLE, C.T.; CORRÊA, B.J.S.; E VIEIRA, F.S. Caracterização morfométrica da bacia hidrográfica do rio Ivaí-Paraná. **Geoambiente On-line**, v.l, n.29, 2018.

STRAHLER, A.N. Hypsometric analysis of erosional topography. **Geological Society of America Bulletin**, [s.l.], n.63, p. 111-1141, 1952.

TONELLO, K.C. **Análise hidroambiental da bacia hidrográfica da cachoeira das Pombas, Guanhães, MG**. 69f. Tese (Doutorado em Ciências Florestais) – Universidade Federal de Viçosa, Viçosa, 2005.

TUCCI, C.E.M. (Org.). Hidrologia: ciência e aplicação. 3. ed. Porto Alegre: Editora da UFRGS/ ABRH, 2004.

VANZELA, L.S.; SOUZA, R.A.de; PITARO, F.A. da M.; SILVA, P.A.F.; SANCHES, A.C. Influência da ocupação do solo e do excedente hídrico sobre a vazão e transporte de sedimentos. **Irriga**, v.1, n.1, p. 181-191, 2012.

VILLELA, S.M.; MATTOS, A. Hidrologia aplicada. São Paulo: McGraw-Hill, 1975.

ZHANG, C.; NEARING, M.A.; GARBRECHT, J.D.; STEINERJ.L. Downscaling monthly forecasts to simulate impacts of climate change on soil erosion and wheat production**. Soil Science Society of America Journal**, v.68, p. 1376-1385, 2004.