Study of morphometry and land coverage to help urban planning in Barbosa and Barbosinha Brooks watershed, Lins - SP

Isadora Vitali Lobo
M.Sc. Student, Civil Engineering Post-Graduation Program, UNESP, Brazil.
isadora.vitali@unesp.br

César Gustavo da Rocha Lima
PhD, Civil Engineering Post-Graduation Program, UNESP, Brazil.
cesar.lima@unesp.br

José Augusto Di Lollo
Full Professor, Civil Engineering Post-Graduation Program, UNESP, Brazil.
jose.lollo@unesp.br

ABSTRACT

Urbanization in hydrographic basins promotes changes in the hydrological cycle through the impermealized areas. Not only surface runoff is increased, reducing infiltration, but also the susceptibility to extreme hydrological events. The objective of this study is to analyze the natural susceptibility of Córregos Barbosa e Barbosinha (Barbosa and Barbosinha Brooks) watershed to flooding. Morphometric parameters of land use and occupation were analyzed, in order to subsidize management and planning in an area of urban expansion. The analysis of land use and occupation was based on the supervised classification method of Landsat-5 Thematic Mapper (TM) sensor and Landsat-8 Operational Land Imager sensor (OLI) satellite images dated 1990, 2006 and 2020. Morphometric indices were calculated using the SPRING 5.4.3 software and a SRTM image with a spatial resolution of 30 meters. The results indicate that the natural susceptibility to flooding of the study area is medium to high, and can be intensified by the dynamics of land use and occupation and increasing impervious areas in the basin. Over the period of study, the growth of impervious areas was 133% relative to 1990.

KEYWORDS: Geographic information system, urbanization, floods.

1 INTRODUCTION

Urbanization causes considerable changes in the hydrological cycle, especially when associated with the impermeabilization of soils in an urban hydrographic basin. As impervious areas increase, maximum discharge also increases at the expense of reduced evapotranspiration and groundwater flow and storage. The increase of the maximum discharge in these urbanized areas can reach values six times higher relatively to those of hydrographic basins of lower levels of urbanization (TUCCI, 2003).

When it comes to urbanization, changes in land use and cover have usually been the main triggering agents of overflowing and flooding in Brazilian urban watersheds. On the other hand, physical and geomorphological conditions inherent to hydrographic basins can make them naturally prone to the effects of such phenomena (BARROS et al., 2016).

Overflowing is a natural event that takes place in the secondary river channels (OLIVEIRA; OLIVEIRA; BARBOSA, 2015). When it happens in populated areas, flooding occurs, and its intensity is directly related to soil impermeabilization in urban areas (GUERRA; ZACHARIAS, 2015).

Along the years, Lins municipality (State of São Paulo, Southeastern Brazil) has faced problems associated with these processes, requiring special attention when they take place in areas within the urban expansion perimeter, such as the region that encompasses the Barbosa and Barbosinha Brooks watershed (LINS, 2018). The municipal sanitation plan requires as necessary information for drainage planning knowledge related to land use and types and physical data regarding the urban hydrographic basins (LINS, 2017).

In this context, the morphometric parameters allow the quantitative characterization of the physical elements of a hydrographic basin, establishing values that describe the intensity of the ongoing processes and helping to understand the dynamics of the transformations occurring in the area of interest (SANTOS et al., 2016).

According to Tucci (2008), the management model adopted by the public power does not encourage the prevention of problems related to overflowing and flooding. The occurrence of these phenomena can be related to certain attitudes, such as lack of restrictions regarding the occupation of flood-prone areas. The Master Plan for Urban Development takes only into account that a sequence of years with no overflowing is favorable to the occupation of urban areas. Another fact to be considered is the occupation of medium risk-prone areas, leading to significant damage when such phenomena take place.

Studies that integrate information obtained when calculating morphometric indices are indispensable for the integrated planning in hydrographic basins, because they give support to environmental management strategies, in face of the variety of possibilities of integration with other factors, such as the dynamics of land use and cover (SOARES et al., 2016).

In this sense, the use of geoprocessing techniques via Geographical Information Systems (GIS) is a powerful tool in the analysis of not only the present situation in urban areas, but also of future projections, aiding urban growth planning and contributing to decision making in the ambit of management and regulation of land use and cover (NASCIMENTO; LIMA; SANTOS, 2009).

2 OBJECTIVES

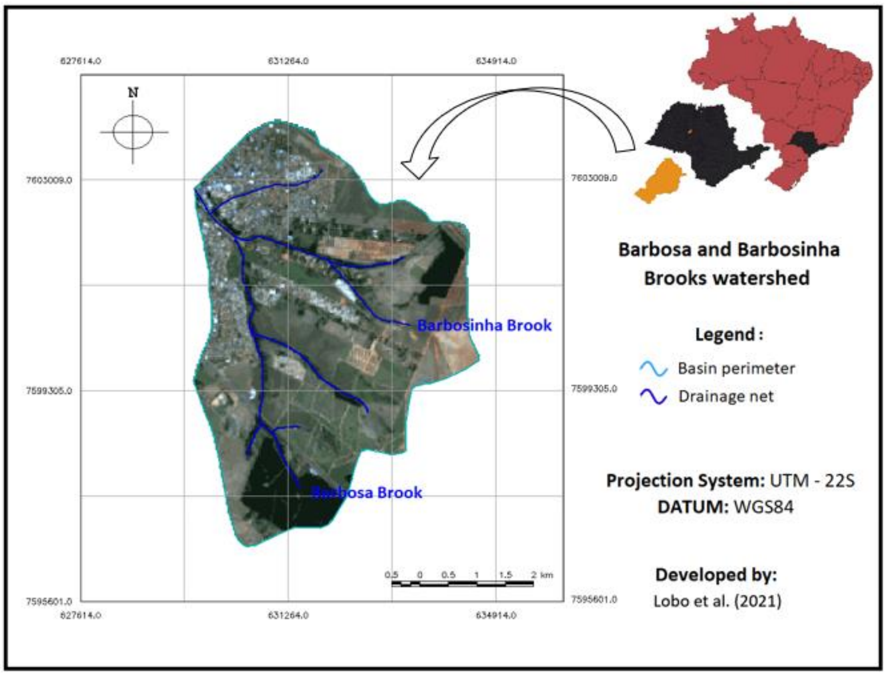
The objective of the present study is to characterize the morphometry and land use and cover of the upper Barbosa Brook watershed, which is totally inserted in the urban area and in areas destined to urban expansion in Lins municipality (State of São Paulo, Southeastern Brazil), by means of GIS techniques and remote sensing, as support to planning and integrated management of the Barbosa and Barbosinha Brooks watershed.

3 METHODOLOGY

3.1 THE STUDY AREA

The hydrographic basin of interest to the study is located in Lins, a municipality inserted in the central-western region of the State of São Paulo (Figure 1).

Figure 1: Study área, Barbosa and Barbosinha Brooks watershed



Source: Prepared by the authors

It is 570.058 km² in area and the estimated number of inhabitants is 78,503, resulting in a demographic density of 124.98 people/km² (IBGE, 2020) and urbanization level of 98.83% (SEADE, 2021).

The characteristic biome is the Atlantic Forest (Mata Atlântica – IBGE, 2019). Soil types are Red, Red-Yellow Latosol and Red-Yellow Ultisols (ROSSI, 2017). The climate, according to Köppen's classification, is Aw (ROLIN et al., 2007) – rainy tropical, with dry winters. Mean temperatures higher than 18 °C characterize the coldest months (DONALISIO et al., 2008).

The basin comprises the Barbosa Brook and the Barbosinha Brook, with a territorial extension of 24.59 km², inserted in an area destined to urban expansion in accordance with the Municipal Master Plan.

3.2 MORPHOMETRIC INDICES

To the extraction of morphometric parameters, a digital terrain model (DTM) was obtained from a Shuttle Radar Topography Mission (SRTM) image of 30-m spatial resolution, acquired via the Earthdata domain of the National Aeronautics and Space Administration (WATKINS, 2000).

With the aid of software SPRING 5.4.3 (CAMARA et al., 1996), a data bank was created with a projection system defined in Universal Transverse Mercator (UTM) coordinates and DATUM WGS84; isolines were generated, after importing the SRTM image and DTM extraction. With the aid of the hydrography reprojected for Lins municipality and acquired via the data bank supporting the rural environmental registration (FBDS, 2018), the drainage net of the Barbosa and Barbosinha Brooks watershed was drawn using vector editing.

Data, such as total length of the water courses (Lt), drainage area (A), perimeter of the basin (P), length of the main canal (Ccp), vectorial distance of the main canal (Dv), and axial length of the basin (L) were obtained with metric operations tools and class measures, in order to calculate the morphometric indices listed in Chart 1.

Chart 1: Equations used in the analysis of the morphometric parameters

Morphometric parameters	Equação	Autor
Drainage density (Dd) - km/km²	$Dd = \frac{Lt}{A}$	RAY; FISCHER (1960)
Compactness coefficient (Kc) - dimensionless	$Kc = 0{,}28\frac{P}{\sqrt{A}}$	VILLELA; MATTOS (1975)
Form factor (Kf) - dimensionless	$Kf = \frac{A}{L^2}$	VILLELA; MATTOS (1975)
Sinuosity Index (Is) - dimensionless	$Is = \frac{C_{CP}}{D_V}$	HORTON (1945)
Circularity Index (Ic) -dimensionless	$Ic = \frac{A}{Ac}$	CHRISTOFOLETTI (1980)

Source: Prepared by the authors

To aid the analysis and interpretation of the results, a main canal section was generated from DTM; a declivity map of the study area using the classification established by Lepsch et al. (1991); a cross tabulation of the declivity data and use and occupation, and the survey of the existing enterprises interested in social housing and potential future occupation of the Barbosa and Barbosinha Brooks watershed.

3.3 LAND USE AND COVER

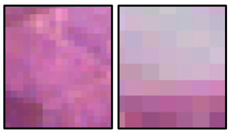
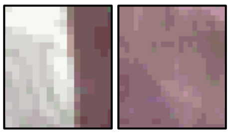
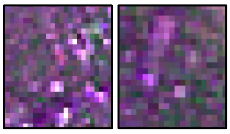
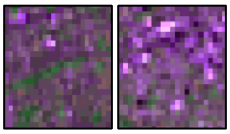
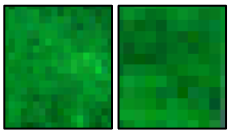
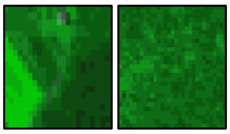
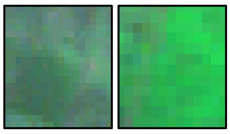
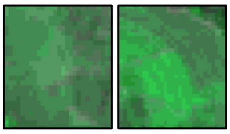
Land use and cover was analyzed for three different years (1990, 2006 and 2020), in order to investigate the changes in the study area through time. The satellite images were selected from an image catalogue of the Instituto Nacional de Pesquisas Espaciais (National Institute of Spatial Research – INPE, 2021). For 1990 and 2006, bands 2, 3, and 4 of the Landsat 5 Thematic Mapper (TM) sensor were selected. For 2020, bands 3, 4, and 5 of Landsat 8 Operational Land Imager (OLI) sensor were chosen. The dates of image acquisition corresponded to the dry season, according to the climatic classification of the study area. Aiming at similar behaviors of use and occupation dynamics in the study area, the following months were chosen: July 1990, September 2006, and August 2020.

The imported and recorded images were processed using software SPRING 5.4.3 (CAMARA et al., 1996). The following color compositions were selected: 3(B)4(R)5(G) for 2020, and 2(B)3(R)4(G) for 1990 and 2006. Contrast was applied to help a better interpretation of the features.

The classification method selected for this study was that supervised by Bhattacharyya regions. The images were segmented in homogeneous regions of similar spectral behavior. The values of similarity and area thresholds adopted for 2020 were respectively 10 and 30. For 1990 and 2006 tests were performed with different similarity threshold values. The best response was obtained with value 5 for 1990 and value 3 for 2006. The area threshold for both 1990 and 2006 was defined as 30.

Training and sample collection were carried out according to the interpretation key as shown in Chart 2.

Chart 2: Use and occupation classes, behavior of the features and description of what they are composed of

Class	Behavior		Description
	Landsat 5 - 2(B)3(R)4(G)	Landsat 8 - 3(B)4(R)5(G)	
Exposed soil			Areas devoid of cover, bare or prepared soil, areas transitional from shrubland and exposed soil.
Impervious areas			Impervious areas, roofs, covers, highways, and buildings.
Arboreal vegetation			Grouped arboreal vegetation, presence of trees of a variety of sizes, silviculture.
Shrubland			Pasture in formation, secondary vegetation, and planting areas.

Source: Prepared by the authors

Image cropping was performed with the help of a polygon generated for the calculation of the morphometric parameters with the basin area. The classifications generated for each year were refined by means of a post-classification, so as to correct inconsistences identified in each one of them.

4 RESULTS AND DISCUSSION

According to the classification of Vale and Bordalo (2020), the resulting type of drainage density for the study area is low (Dd = 0.70 km/km², value less than 1.5), which is characterized by higher infiltration and slower runoff. This factor can positively contribute to the local dynamics of the hydrological processes, allied to the soil types present in the basin, which in general are correlated with good drainage (SOUZA; LOBATO, 2004); however, this is not an isolated factor, and should be assessed together with other parameters (SANTOS; CARVALHO; ANTONELI, 2016).

The result and classification are compatible with those obtained by other authors. Pereira and Mendes (2018) obtained a Dd value of 1.15 km/km², which indicates that infiltration conditions in the Iguaçu-Sarapuí river basin (State of Rio de Janeiro) are good. França et al. (2013) classified the Carão hydrographic basin (State of Ceará) as of low drainage capacity, as the Dd value obtained for that region was 0.78 km/km².

Contrarily to what was indicated by the drainage density, the sinuosity index (Is) obtained for the study area was 1.09, which indicates that the main canal tends to be rectilinear and of higher flow velocity. Barros et al. (2016) relates the rectilinear shape and higher flow velocity to high probability of overflowing and flooding. These authors analyzed four different sub-basins located in the Prata River (Maranhão Island) and obtained Is values from 1.06 to 1.19, classifying all canals as rectilinear and subjected to these phenomena.

The compactness coefficient (Kc) obtained for the study area was 1.19, indicating that watershed shape tends to be circular, indicating highly tendency to overflowing (NARDINI et al., 2013; VALE; BORDALO, 2020). Ribeiro and Pereira (2013) obtained a Kc value of 1.27 for the Vargens de Caldas hydrographic basin (State of Minas Gerais), also indicative of circular shape. Fritzsons and Mantovani (2010), when analyzing the Campestre and the Várzea do Capivari sub-basins, obtained Kc values respectively of 1.17 and 1.16. During field work, the authors observed that overflowing was frequent in sites located close to the outlets of both basins. This can be related to the fact that in circular basins the probability of intense rainfall occurring simultaneously throughout them is high, concentrating large volumes of water in their main tributary (CARDOSO et al., 2006).

According to Lima et al. (2013), form factor (Kf) values falling in different intervals enables the classification of a hydrographic basin according to its tendency to overflowing: Kf values falling in the 0.75-1.00 range indicate that the basin is prone to overflowing; Kf values falling in the 0.75-0,50 range indicate moderate tendency to overflowing, and Kf less than 0.5 indicate no tendency to overflowing. The Kf value of 0.62 obtained for the study area indicates moderate tendency to overflowing. Alves da Silva and Duarte (2020) observed the same tendency in the Espinharas river sub-basin (State of Paraíba), indicated by a Kf value of 0.68.

Circularity index (Ic) may vary from 0 to 1. Hydrographic basins with high Ic values are: prone to water level rising (SANTOS; CARVALHO; ANTONELI, 2016); more vulnerable to overflowing (BARROS et al., 2016), and more subjected to flooding (SILVA et al., 2018). The Ic value obtained for the study area was 0.69, pointing to a circular shape, more susceptible to flooding. This result is compatible with the characteristics reported for different Ic values by Franco and Santo (2015): Ic values less than 0.51 correspond to elongated shapes, favoring runoff; values greater than 0.51 correspond to circular shapes, contributing to flooding, and values equal to 0.51 correspond to moderate runoff with little probability of water level rising.

The morphometric indices for the Barbosa Brook watershed are presented in Table 1.

Table 1: Results of the morphometric indices obtained for the Barbosa and Barbosinha Brooks basin.

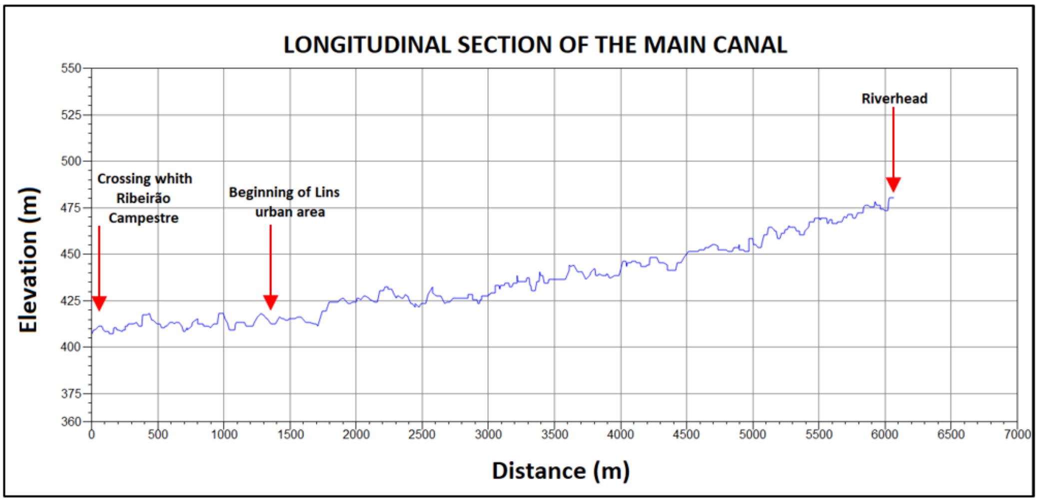
Morphometric parameters	Results	Natural susceptibility to overflowing and flooding
Total length of water courses (Lt)	17.27 km	
Drainage area (A)	24.59 km²	
Perimeter of the basin (P)	21.12 km	
Axial Length of the basin (L)	6.28 km	
Length of the main canal (Ccp)	6.07 km	
Vectorial distance (Dv)	5.54 km	
Drainage density (Dd)	0.70 km/km²	
Compactness coefficient (Kc)	1.19	
Form factor (Kf)	0.62	
Sinuosity Index (Is)	1.09	
Circularity Index (Ic)	0.69	

Low susceptibility Moderate susceptibility High susceptibility ;

Source: Prepared by the authors

The combined analysis of the main canal section presented in Figure 2 indicates a natural circular tendency for the Barbosa and Barbosinha Brooks watershed, attested by the morphometric indices. This is a worrying factor, because less-steep areas, identified by smaller level differences and extending for approximately 1.276 km, are prone to water accumulation and are totally inserted in impervious urban areas close to the drainage outlet and to points where overflowing occurs in Lins municipality.

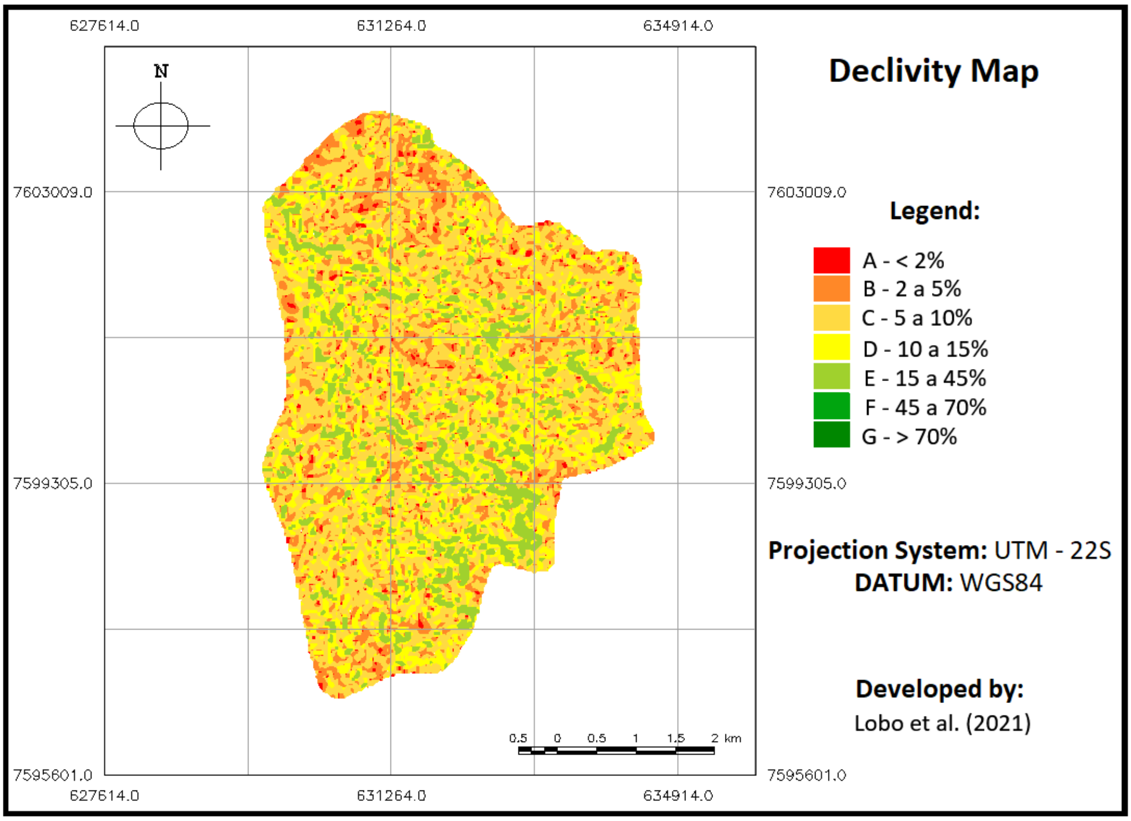
Figure 2: Longitudinal main canal section from downstream to upstream.



Source: Prepared by the authors

Another important factor related to the study area is that the predominant declivity class, according to Lepsch et al. (1991), is class C, of declivity values between 5 and 10%, which extends for ca. 10.44 km² and corresponds to ca. 42.5% of the total area of the basin. The predominant characteristics of class C are steeper areas, undulating relief, and moderate to fast runoff on most of the soil types. The distribution of the declivity classes along the Barbosa and Barbosinha Brooks watershed are represented in the declivity map of Figure 3.

Figure 3: Declivity map for the Barbosa and Barbosinha Brooks watershed



Source: Prepared by the authors

The combined analysis of the morphometric parameters indicates that the susceptibility to overflowing and flooding in the study area is naturally moderate to high. In turn, the declivity map and the main canal section indicate that runoff can cause damage to the basin, because of its intensity and water accumulation in less steep regions.

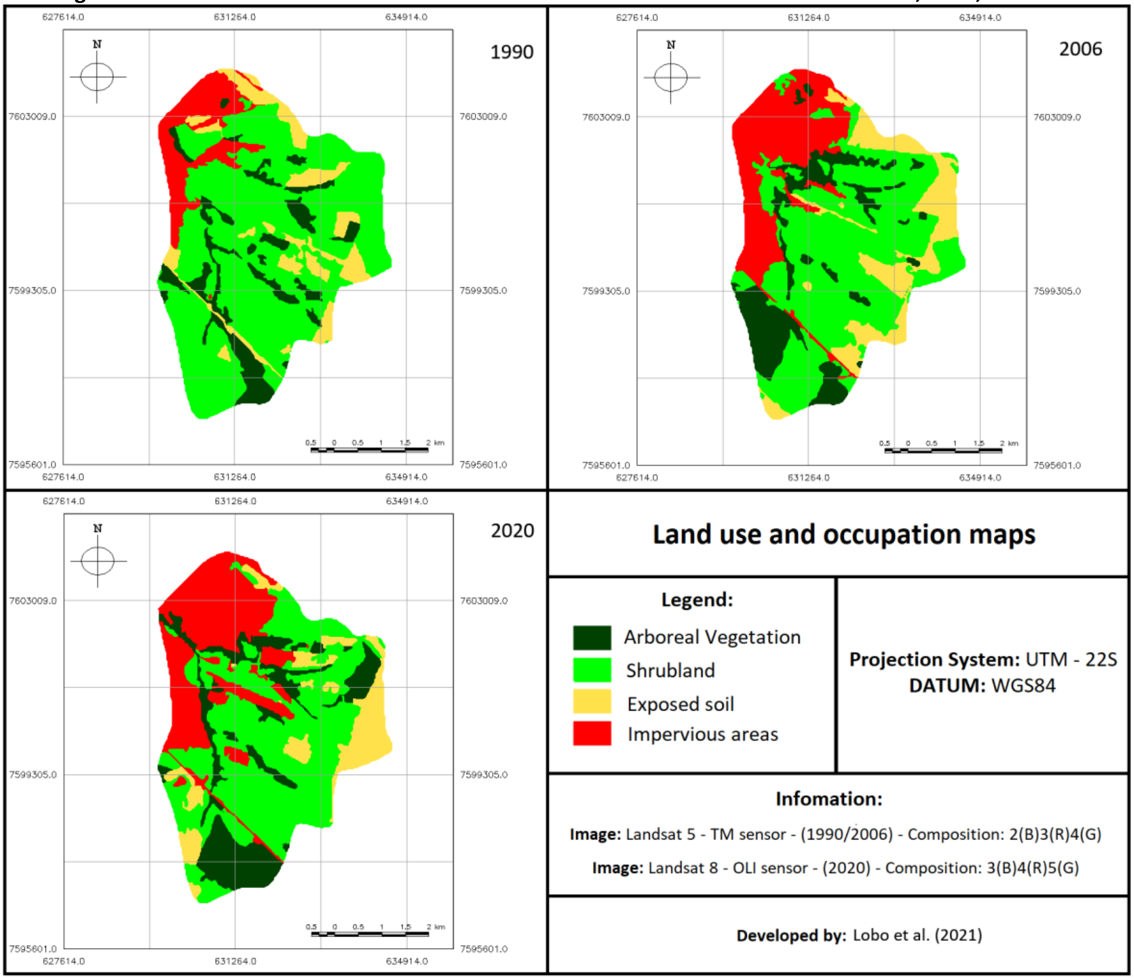
These results demonstrate that a better knowledge of the land use and occupation in the area of interest is a primordial factor to the understanding of the dynamics of the hydrological processes operating inside the basin, once the pressures exerted by them, via changes in natural characteristics, directly influence the occurrence of such phenomena. The combined analysis of morphometric parameters and land use and occupation information is highlighted in a variety of studies (SILVA; MEDEIROS, 2017; OLIVEIRA; ACORSI; SMANIOTTO, 2018; BEGA; RIBEIRO; LIMA, 2019; NOBRE et al., 2020).

An estimate of changes in behavior was attempted for the study area by means of the analysis of land use and occupation. The adopted methodology classified the study area in four different groups, on the basis of its permeability characteristics, resulting in the following

Periódico Eletrônico
Fórum Ambiental da Alta Paulista
ISSN 1980-0827 – Volume 17, número 6, 2021

classes: impervious areas, exposed soil, shrubland, and arboreal vegetation. Resulting from this classification, areal quantities were obtained for each class for 1990, 2006, and 2020 and are presented in the use and cover maps of Figure 4.

Figure 4: Land use and cover in the Barbosa and Barbosinha Brooks watershed in 1990, 2006, and 2020



Source: Prepared by the authors

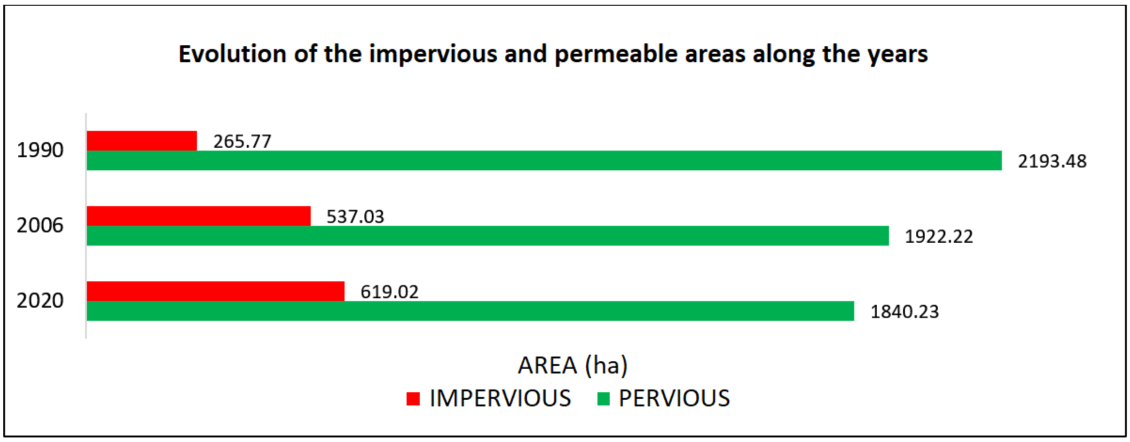
The analysis of the use and cover maps indicated that along the years the Barbosa and Barbosinha Brooks watershed has undergone changes regarding urban expansion and increase of impervious areas upstream the drainage outlet. In 2006, these areas increased ca. 102% in comparison to 1990. In 2020, such increase, relative to 2006, was of approximately 15%. From 2006 to 2020, the increase was 133%, as shown in Table 2 and the graph of Figure 5.

Table 2: Land use and occupation in the Barbosa and Barbosinha Brooks watershed in 1990, 2006, and 2020

Use and Occupation	Area (ha)			Variation Percentage (%)		
	1990	2006	2020	1990 - 2006	2006 - 2020	1990 - 2020
Impervious areas	265.77	537.03	619.02	102%	15%	133%
Arboreal vegetation	307.89	355.95	422.19	16%	19%	37%
Shrubland	1594.44	1196.1	1127.7	-25%	-6%	-29%
Exposed soil	291.15	370.17	290.34	27%	-22%	-0.3%
Total	**2459.25**	**2459.25**	**2459.25**			

Source: Prepared by the authors

Figure 5: Land use and occupation in 1990, 2006, and 2020



Source: Prepared by the authors

The results of the cross tabulation of land use and occupation classes and the declivity map are presented in Table 3. The iteration of the data makes it possible to analyze the behavior of the declivity in each land use and occupation class group. For the analysis, the results of the use and cover classification for 2020 were used. It is observed that the impervious areas are mostly located in regions of declivity varying from classes D (114.48 ha), B (147.51 ha), and C (269.19 ha), respectively corresponding to following runoff characteristics: fast, slow to intermediate, and intermediate to fast, representing, together with soil impermeabilization, risk to overflowing and flooding.

Table 3: Cross tabulation of declivity and land use and occupation for 2020

Declivity	Classes (ha)			
	Impervious areas	Exposed soil	Arboreal vegetation	Shrubland
A - < 2%	33.39	13.23	18.81	45.72
B - 2 a 5%	147.51	62.10	78.03	195.93
C - 5 a 10%	269.19	119.07	171.45	443.07
D - 10 a 15%	114.48	68.49	107.01	288.81
E - 15 a 45%	47.16	24.57	48.87	148.77

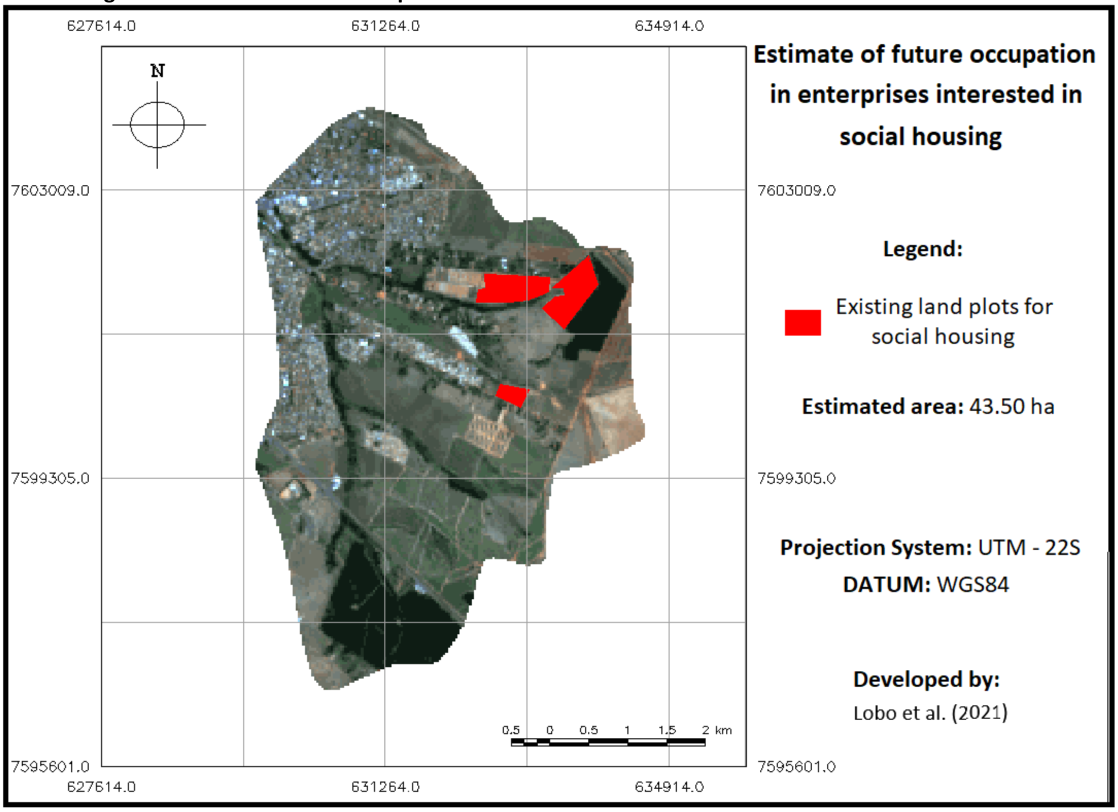
Source: Prepared by the authors.

In parallel to this information, cross tabulation shows that most of the areas that correspond to other use and occupation classes fall in classes D, B, and C, in ascending order, corroborating the tendency to intermediate to fast runoff and indicating that the replacement of these types of classes by impervious areas along the years will probably cause damage due to increasing runoff in steeper areas and consequently greater subjection of the study are to overflowing and flooding.

The replacement of permeable areas impervious areas along the years is expected, as they are located within the urban expansion perimeter of Lins municipality. Field work and satellite images (Google Earth, 2021) have shown that there is a tendency of increasing the impervious areas, once land plots already implemented in the study area are not totally occupied.

A survey of the areas to be occupied was carried out adopting as parameter the already implemented land plots and those predicted in the Lins Municipal Master Plan for social housing, characterized by a denser occupation. It is possible to estimate that in the future the impervious areas can exceed 43.50 ha the value presented for land use and occupation in 2020, as shown in Figure 6.

Figure 6: Estimate for future impervious areas in the Barbosa and Barbosinha Brooks watershed



Source: Prepared by the authors

This is a fact of great concern, once the analysis of morphometric parameters indicates a natural susceptibility of the study area to overflowing. Besides, the data interpreted from the cross tabulation indicate possible increase in fast-moving runoffs resulting from the replacement of areas of exposed soil, arboreal vegetation, and shrubland by impervious areas. The main canal section indicates tendency of water accumulation in urban areas close to the drainage outlet, included in the mapping of areas prone to flooding and overflowing in the Lins Municipal Master Plan (LINS, 2018).

5 CONCLUSIONS

By means of the analysis of morphometric parameters, a tendency of natural susceptibility to overflowing and flooding was identified in the study area. The propensity to a circular shape can directly influence the runoff spatial distribution. Because of the compact shape, runoff from different parts of the basin tends to be directed to the main canal at the same time, causing decrease in concentration time and accelerating the arrival of the entire discharge to the drainage outlet. The drainage outlet is located in the urban area, in a region of low declivity and related to the occurrence of overflowing and flooding.

The analysis of land use and occupation parameters showed that the Barbosa and Barbosinha Brooks watershed has experienced an increase in urbanized areas along the years, reaching an increase of 133% in impervious areas from 1990 to 2020, representing the replacement of permeable by impervious areas. In view of the analysis of declivity data by use and occupation classes, this trend can corroborate the vulnerability of the basin to the occurrence of extreme hydrological events.

The use of geoprocessing and geographical information systems for this type of integrated analysis represent advantages regarding low costs and the comprehensive analysis, helping identify the characteristics inherent to the hydrographic basin that trigger the occurrence of such events and decision making and management of the areas of interest.

6 REFERENCES

ALVES DA SILVA, J. B.; DUARTE, S. M. A. Caracterização morfométrica da sub-bacia do Rio Espinharas no estado da Paraíba-PB. **Revista Técno-Lógica**, v. 24, n. 1, p. 112-116, 2020. Disponível em: <http://twixar.me/3LRm>. Acesso em: 27 mai. 2021.

BARROS, D. V. et al. Morfometria, uso e cobertura do solo como indicadores de enchentes e inundações na Bacia do Rio do Prata, Ilha do Maranhão. **Revista Brasileira de Gestão Ambiental e Sustentabilidade**, v. 3, n. 5, p. 217-226, 2016. Disponível em: <http://twixar.me/VDRm>. Acesso em: 12 jun. 2021.

BEGA, J. M. M.; RIBEIRO, N. U. F.; LIMA, C. G. R. Suscetibilidade a enchentes: estudo de caso na microbacia hidrográfica do Córrego da Onça em Três Lagoas - MS. **Periódico Eletrônico Fórum Ambiental da Alta Paulista**, v. 15, n. 3, 2019. Disponível em: <http://twixar.me/vsRm>. Acesso em: 26 jun. 2021.

CAMARA G. et al. **SPRING: Integrating remote sensingand GIS by object-oriented data modelling. Computers & Graphics**, v. 20, n. 3, p. 395-403, 1996.

CARDOSO, C. A. et al. Caracterização morfométrica da bacia hidrográfica do Rio Debossan, Nova Friburgo, RJ. **Revista Árvore**, v. 30, n. 2, p. 241-248, 2006. Disponível em: <http://twixar.me/y3Pm>. Acesso em: 09 jun. 2021.

CHRISTOFOLETTI, A. **Geomorfologia**. São Paulo: Edgard Blücher, 1980, 188p.

DONALISIO, M. R. et al. Aspectos climáticos em áreas de transmissão de hantavirose no Estado de São Paulo, Brasil. **Cadernos de Saúde Pública**, v.24, p. 1141-1150, 2008. Disponível em: <http://twixar.me/QvRm>. Acesso em: 13 jun. 2021.

FRANÇA, J. M. B. et al. Morfometria e uso e ocupação da bacia hidrográfica do Carão, Estado do Ceará, Brasil. In: Simpósio Brasileiro de Sensoriamento Remoto – SBSR, 16., 2013, Foz do Iguaçu. **Anais [...]**. Foz do Iguaçu: INPE, 2013. p. 8138-8145. Disponível em: <http://twixar.me/zDRm>. Acesso em: 27 mai. 2021.

FRANCO, A. C. V.; SANTO, M. A. D. Contribuição da Morfometria Para o Estudo das Inundações na Sub-Bacia do Rio Luís Alves/SC. **Mercator**, v. 14, n. 3, p. 151-167, 2015. Disponível em: <http://twixar.me/4LRm>. Acesso em: 21 mai. 2021.

FRITZSONS, E.; MANTOVANI, L. E. Os substratos geológicos e os coeficientes morfométricos em bacias hidrográficas do carste dolomítico no Estado do Paraná. **Revista Brasileira de Geografia Física**, v. 3, p. 181-189, 2010. Disponível em: <http://twixar.me/KFRm>. Acesso em: 27 mai. 2021.

Fundação Brasileira para o Desenvolvimento Sustentável (org.) - FBDS. **Mapas: hidrografia. Hidrografia**. Rio de Janeiro, 2018. Disponível em: <http://twixar.me/QcRm>. Acesso em: 17 jun. 2021.

Fundação Sistema Estadual de Análise de Dados (org.) - SEADE. **Perfil dos municípios paulistas**. São Paulo, 2021. Disponível em: <http://twixar.me/xvRm>. Acesso em: 13 jun. 2021.

GOOGLE. **Google Earth Pro**. Disponível em: <http://twixar.me/b3Pm>. Acesso em: 25 mai. 2021.

GUERRA, F. C.; ZACHARIAS, A. A. O mapeamento das áreas vulneráveis aos riscos ambientais e as políticas públicas municipais para a sustentabilidade do patrimônio ambiental urbano. **Revista Geografia e Pesquisa**, v. 9, n. 1, p. 66-75, 2015. Disponível em: <http://twixar.me/dhRm>. Acesso em: 12 jun. 2021.

HORTON, R. E. Erosional development of streams and their drainage basins: Hydrographical approach to quantitative morphology. **Geological Society of America Bulletin**, v. 56, n. 2, p. 275-370, 1945.

Instituto Brasileiro Geografia Estatística (org.) – IBGE. **Censo. IBGE Cidades. População**. IBGE, Instituto Brasileiro de Geografia e Estatística, 2020. Disponível em: <http://twixar.me/6vRm>. Acesso em: 13 jun. 2021.

Instituto Brasileiro Geografia Estatística (org.) – IBGE. **Censo. IBGE Cidades. Território e Ambiente**. IBGE, Instituto Brasileiro de Geografia e Estatística, 2019. Disponível em: <http://twixar.me/6vRm>. Acesso em: 13 jun. 2021.

Instituto Nacional de Pesquisas Espaciais – INPE (org.). **Catálogo de Imagens**. Disponível em: <http://twixar.me/w3Pm>. Acesso em: 19 mai. 2021.

LEPSCH, I.F. et al. **Manual para levantamento utilitário do meio físico e classificação de terras no sistema de capacidade de uso**. 4a Aproximação. 2. ed. Campinas: Sociedade Brasileira de Ciência do Solo, 1991. 175p.

LIMA, G. C. et al. Estimativa do potencial de recarga na Sub-bacia das Posses, Extrema (MG), em função dos atributos fisiográficos, pedológicos e topográficos. **Geociências**, v. 32, n. 1, p. 51-62, 2013. Disponível em: <http://twixar.me/kDRm>. Acesso em: 27 mai. 2021.

LINS. Prefeitura Municipal de Lins-SP. **Plano Diretor do Município – Relatórios.** Lins, SP, 2018. Disponível em: <http://twixar.me/zNRm>. Acesso em: 13 jun. 2021.

LINS. Prefeitura Municipal de Lins-SP. **Plano Municipal de Saneamento Básico**. Lins, SP, 2017. Disponível em: <http://twixar.me/zNRm>. Acesso em: 13 jun. 2021.

NARDINI, R. C. et al. Análise morfométrica e simulação das áreas de preservação permanente de uma microbacia hidrográfica. **Irriga**, v. 18, n. 4, p. 687-699, 2013. Disponível em: <http://twixar.me/xDRm>. Acesso em: 12 jun. 2021.

NASCIMENTO, V. M. L. C.; LIMA, E. R. V.; SANTOS, C. A. G. SIG na avaliação de áreas para ocupação urbana de João Pessoa, PB. **Ambiente Construído**, v. 9, n.1, p. 107-123, 2009. Disponível em: <http://twixar.me/ghRm>. Acesso em: 12 jun. 2021.

NOBRE, N. C. et al. Caracterização morfométrica, climática e de uso do solo da Bacia hidrográfica do rio Farinha-MA. **Acta Iguazu**, v.9, n.1, p. 11-34, 2020. Disponível em: <http://twixar.me/lsRm>. Acesso em: 26 jun. 2021.

OLIVEIRA, D. H. R.; ACORSI, M. G.; SMANIOTTO, D. A. Uso e ocupação do solo e caracterização morfométrica de microbacia na região centro-sul paranaense. **Águas Subterrâneas**, v. 32, n. 2, p. 1-10, 2018. Disponível em: <http://twixar.me/ZsRm>. Acesso em: 26 jun. 2021.

OLIVEIRA, T. J. V. de. S.; OLIVIERA, G. M.; BARBOSA, A. A. Histórico de enchentes em Itajubá/MG. **Revista Meio Ambiente e Sustentabilidade**, v. 9, n. 4, p. 125-140, 2015. Disponível em: <http://twixar.me/1hRm>. Acesso em: 12 jun. 2021.

PEREIRA, P. S. M. L. P.; MENDES, L. D. Morfometria de bacia hidrográfica urbanizada: Uma análise do Rio Iguaçu-Sarapuí, na Baixada Fluminense (RJ), para avaliação de parâmetros de suscetibilidade à ocorrência de enchente e inundação. **Revista Continentes**, n. 13, p. 34-48, 2018. Disponível em: <http://twixar.me/5DRm>. Acesso em: 27 mai. 2021.

RAY, R. G.; FISCHER, W. A. **Quantitative photography, a geologic research tool. Photogrammetric Engineering, Washington**, v.26, p. 143-150, 1960.

RIBEIRO, G. F.; PEREIRA, S. Y. Análise morfométrica da bacia hidrográfica Vargens de Caldas, Planalto de Poços de Caldas, MG. **Terrae**, v. 10, n. 1-2, p. 15-20, 2013. Disponível em: <http://twixar.me/CDRm>. Acesso em: 27 mai. 2021.

ROLIN, G. S. et al. Classificação climática de Köppen e de Thornthwaite e sua aplicabilidade na determinação de zonas agroclimáticas para o estado de São Paulo. **Bragantia**, v. 66, n. 4, p. 711-720, 2007. Disponível em: <http://twixar.me/MvRm>. Acesso em: 12 jun. 2021.

ROSSI, M. **Mapa Pedológico do Estado de São Paulo: revisado e ampliado.** São Paulo: Instituto Florestal. 2017, v. 1, 118 p. Disponível em: <http://twixar.me/NcRm>. Acesso em: 13 jun. 2021.

SANTOS, M. A.; CARVALHO, S. M.; ANTONELI, V. Suscetibilidade a enchentes a partir da análise de variáveis morfométricas, na Bacia Hidrográfica Rio Bonito em Irati-PR-Brasil. **Revista Equador**, v. 5, n. 5, p. 152 – 167, 2016. Disponível em: <http://twixar.me/nsRm>. Acesso em: 17 jun. 2021.

SANTOS, V. S. et al. Uso dos parâmetros morfométricos na bacia hidrográfica do Rio Jaguari/RS em estudos geoambientais. In: Simpósio Nacional de Geomorfologia - UGB, 11., 2016, Maringá. **Anais [...]**. Maringá: UGB, 2016. Disponível em: <http://twixar.me/2FRm>. Acesso em: 27 mai. 2021.

SILVA, C. O. F.; MEDEIROS, G. A. Avaliação ambiental e morfométrica da bacia do rio Jundiaí-Mirim: diagnósticos e subsídios para gestão ambiental. **Boletim Campineiro de Geografia**, v. 7, n. 2, p. 441-454, 2017. Disponível em: <http://twixar.me/LsRm>. Acesso em: 17 jun. 2021.

SILVA, G. C. et al. Caracterização morfométrica da bacia hidrográfica do Riacho Rangel-Piauí, Brasil**. Enciclopédia Biosfera**, v. 15, n. 28, p. 244-258, 2018. Disponível em: <http://twixar.me/0LRm>. Acesso em: 21 mai. 2021.

SOARES, L. S. et al. Análise morfométrica e priorização de bacias hidrográficas como instrumento de planejamento ambiental integrado. **Revista do Departamento de Geografia**, v. 13, p. 82-100, 2016. Disponível em: <http://twixar.me/DhRm>. Acesso em: 12 jun. 2021.

SOUZA, D. M. G.; LOBATO, E. **Cerrado: Correção do solo e adubação**. 2 ed. Brasília: Embrapa Informação Tecnológica. 2004, 416 p. Disponível em: <http://twixar.me/3sRm>. Acesso em: 17 jun. 2021.

TUCCI, C. E. M. Águas urbanas. **Estudos Avançados**, v. 22, n. 63, p. 97-112, 2008. Disponível em: <http://twixar.me/ttmm>. Acesso em: 12 jun. 2021.

TUCCI, C. E. M. Drenagem Urbana. **Ciência e Cultura**, v. 55, n. 4, pág. 36-37, 2003. Disponível em: <http://twixar.me/HWlm>. Acesso em: 12 jun. 2021.

VALE, J. R. B.; BORDALO, C. A. L. Caracterização morfométrica e do uso e cobertura da terra da bacia hidrográfica do Rio Apeú, Amazônia Oriental. **Revista Formação**, v. 27, n. 51, p. 313-335, 2020. Disponível em: <http://twixar.me/RDRm>. Acesso em: 4 jun. 2021.

VILLELA, S.M.; MATTOS, A. **Hidrologia aplicada**. São Paulo: Mcgraw Hill, 1975. 250p.

WATKINS, Derek. **Downloader de bloco SRTM de 30 metros. Ladrilho: S22W050**. 2000. Disponível em: <http://twixar.me/43Pm>. Acesso em: 25 de maio 2021.