SEDIMENT TRANSPORT POTENTIAL OF CONTRIBUTING BASINS OF TERRA RONCA'S KARST SYSTEM

POTENCIAL DE TRANSFERÊNCIA DE SEDIMENTOS DAS BACIAS CONTRIBUINTES DO SISTEMA CÁRSTICO TERRA RONCA

POTENTIEL DE TRANSFERT DES SEDIMENTS DE LES BASSINS CONTRIBUTEURS DU SYSTÉME KARSTIQUE TERRA RONCA

Ana Caroline da Silva Faquim – Universidade Federal de Goiás – Goiânia – Goiás – Brasil
anacarolinefaquim@gmail.com

Márcio Henrique de Campos Zancopé – Universidade Federal de Goiás – Goiânia – Goiás – Brasil
zancope@ufg.br

Luis Felipe Soares Cherem – Universidade Federal de Goiás – Goiânia – Goiás – Brasil
luis.cherem@gmail.com

Abstract

The potential of sediment transfer (PTS) index estimates the capacity of the drainage network to transport its sedimentary load. This paper calculates and compares the PTS of the basins of 2nd, 3rd e 4th hierarchical order, which channels drain into and provides sediments to the caves of the State Park Terra Ronca (PETeR), in the northeast of Goiás. It has been identified 438 basins of 2nd order with low PTS value out of a total of 863; 83 basins of 3rd order with moderate value out of 194 , and 16 basins of 4th order out of 37. The basins of the study area showed moderate to low capacity to supply sedimentary load to caves of the PETeR.
Keywords: Morphometric parameters, drainage network, fluvial geomorphology.

Resumo

O Índice de Potencial de Transferência de Sedimentos (PTS) estima a capacidade da rede de drenagem transportar sua carga sedimentar. Este trabalho calcula e compara o PTS de bacias de 2ª, 3ª e 4ª ordem hierárquica, cujos canais drenam e proveem sedimentos para dentro das cavernas do Parque Estadual Terra Ronca (PETeR), no nordeste de Goiás. Identificou-se 438 bacias de 2ª ordem com baixo valor de PTS em um total de 863 bacias, 83 bacias de 3ª ordem de valor médio em um total de 194 bacias, e 16 bacias de 4ª ordem com valor médio em um total de 37 bacias de hierárquica. As bacias hidrográficas da área têm capacidade moderada a baixa de lançar sedimentos nas cavernas do PETeR.
Palavras-chave: Parâmetros Morfométricos, Rede de drenagem, Geomorfologia fluvial.

Résumé

L'indice du Potentiel de Transfert des Sédiments (PTS) estime la capacité de transport sedimentaire dans les bassin versants. Cette étude calcule et compare le PTS des bassins de 2e, 3e et 4e ordre hiérarchique fluvial, dont les fleuves drainent et fournissant des sédiments vers les les grottes du Parque Estadual de Terra Ronca (PETeR), dans le nord-est de Goias. Le resultats montrent que il y a 438 bassin de 2e ordre à faible valeurs de PTS entre un total de 863 bassins; 83 bassins de 3e ordre des moyennes valeur entre un total de 194 bassins

; et 16 bassins de 4e ordre des moyennes valeur entre un total de 37 bassins. Les bassin versants de la region ont une capabilité modérée à faible de fournir des sediments vers les grottes du PETeR._
Mots-clés: Morphométriques paramètres, bassin versants, géomorphologie fluviale.

Introduction

Scientific research on river drainage systems plays a major role in fostering understanding on landscape dynamics. According to Christofoletti (1980), the analysis of drainage systems can shed light on several geomorphological issues, given that the most active processes of landscape formation take place in rivers.

River systems transport water and sediments from drainage basins; some of them, as a result of geographical features, have greater capacity for transporting water and sediments than others (Latrubesse et al, 2009). An analysis capable of uncovering hydrological and sedimentary behaviour in drainage basins, particularly over the course of the drained area, may be performed via the application of morphometric parameters (Meliani, 2006). Integrating such parameters may elucidate the environmental diversity associated with morphometric features in drainage basins, e.g. sediment transport capacity (Zancopé; Bayer, 2012).

Research studies which address these topics are crucial for the territorial planning of drainage basins in that they help establish guidelines for the use and occupation of land and water resources. Particularly with regard to water resources planning, understanding sediment transport dynamics via rivers is a crucial step towards mitigating the aggradation of channels and reservoirs. Such studies are often combined with the mapping of aggradation deposits (Zancopé; Goncalves; Bayer, 2015).

This research scenario also includes river channels which flow partly through caves, whose deposits cannot be mapped via remote sensing. This is the case of the karstic relief to the east of Vão do Paranã, in Goiás state, Brazil (Latrubesse et al., 2006), where the Terra Ronca State Park (TRSP) is located. The park houses seven of the thirty largest caves in Brazil (Mateucci et al, 2001).

Water and sediment discharges from Serra Geral de Goiás flow into TRSP's cave systems under intense morphodynamic action (Zancopé; Momoli; Bayer, 2013). They are transported by springs which run from the Serra Geral and cross the park's karst until reaching the sinkholes located inside the caves. Injecting sediments into the park's sinkholes

may lead to caves' partial or total obstruction, as has been demonstrated by Laureano, Karmann, and Granger (2013), depending on the sediment volume being transported upstream by the drainage system. Therefore, finding out which drainage basins are most capable of injecting large sediment volumes in TRSP caves becomes a major step towards improving the management of the park as well as of its surrounding buffer zone.

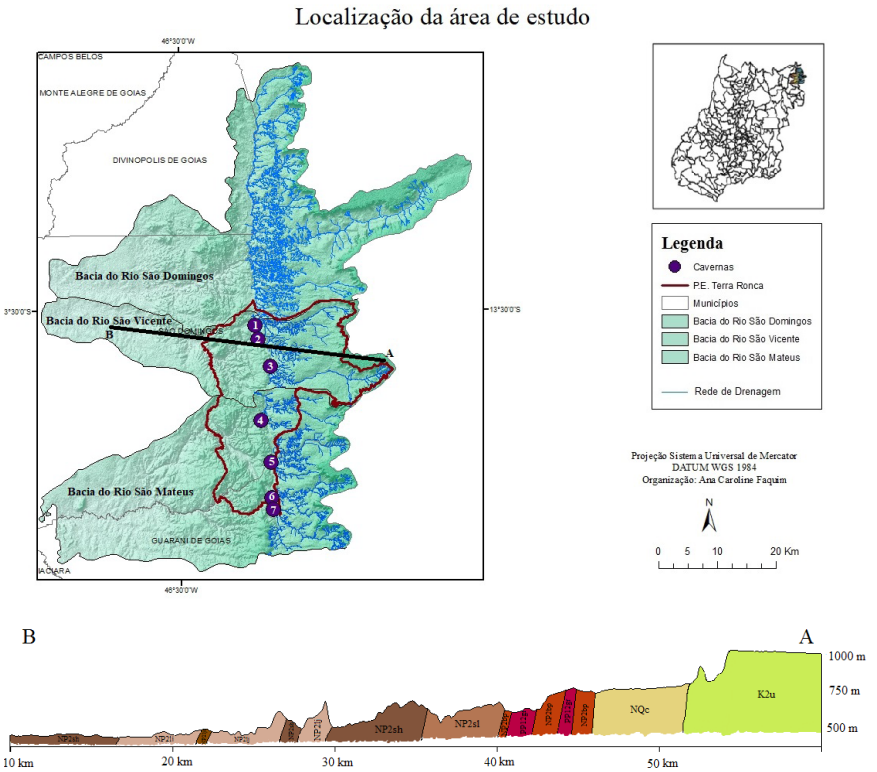
This paper offers an assessment of the sediment transport potential (STP) of drainage basins transporting sediments to Terra Ronca's karst system. The São Domingos, São Vicente, and São Mateus river basins were submitted to the STP index's calculation and analysis due to the fact that they flow across the TRSP, while the park's caves function as a river mouth to the contributing basins as regards STP.

Materials and method

Surveyed area

The surveyed area is located in the municipality of São Domingos, in northeastern Goiás, and covers the middle and upper drainage basins of the São Domingos, São Vicente, and São Mateus rivers, home to the Terra Ronca State Park (TRSP). This area was chosen because the rivers' middle- and upper-reach sub-basins are located upstream of the karst system, hence potentially depositing sediments in the park's caves.

To the east of the selected area lie the slopes of the Serra Geral de Goiás, at the intersection of Goiás and Bahia states. At the top of the mountain range are Bahia's Western Plateaus [Chapadões do Oeste], supported by sandstones of the Urucuia Group, which consist of aquifers that serve river springs in Goiás (CPRM, 2012). Rivers emerging from streams on the Serra Geral slopes flow westward, forming the tributaries on the right bank of the Paranã river. These rivers' upper reaches flow past flat terraces embedded at the foot of Serra Geral, supported by Tertio-Quaternary sandy detritus coverings until they reach the limestone outcrops of the Bambuí Group (Brasil, 1982). Before reaching the Paranã river and while running through the rocks of the Bambuí Group, these rivers develop subterranean sections, thus favouring the speleogenesis of Terra Ronca's karst system as well as relief forms characterized by the chemical dissolution of rocks; the latter promotes the formation of caves, underground galleries with various speleothems, dolines, mogotes, etc. (Latrubesse; Carvalho, 2006).



Cenozóico	**NQc** – Depósitos colúvio-eluviais	Depósitos de areia, depósitos de cascalho, depósitos de argila, laterita.
Mesozóico	**K2U** – Grupo Urucuia	Conglomerado, Arenito conglomerático, Pelítico, Arenito.
Proterozóico	**NP2ljc** – Grupo Bambuí – Formação Lagoa do Jacaré – Fáceis Calcário	Calcário, intercalações de siltitos e margas.
	NP2lj – Grupo Bambuí – Formação Lagoa do Jacaré	Intercalações cíclicas de siltitos e margas com lentes e/ou camadas de calcários pretos.
	NP2sh – Grupo Bambuí – Subgrupo Paraopeba – Formação Serra de Santa Helena	Folhelhos e siltitos com intercalações de arenitos finos e calcários.
	NP2sl – Grupo Bambuí – Subgrupo Paraopeba – Formação Sete Lagoas	Pelitos e margas, com intercalações de lentes de calcários e dolomitos com estruturas estromatolíticas.
	NP2bp – Grupo Bambuí – Subgrupo Paraopeba	Calcarenito, arcóseo, dolomito, siltito, folhelho, argilito, rocha pelítica rítmica, marga.
	PP12gr – Complexo Almas – Cavalcante – Unidade Ortognáissica	Granito, tonalito, trondhjemito, Quartzo diorito, Quartzo monzodiorito, granodiorito.

Figure 1. Location of surveyed area. Source: SIEG, 2016 – 2017. 1 – Cave of Angélica creek; 2 – Cave of Bezerra brook; 3 – Cave of São Vicente river; 4 – Cave of São Mateus river; 5 – Cave of Lapa river (Terra Ronca); 6 – Cave of Palmeiras creek; 7 – Cave of São Bernardo river.

Methodological procedures

The sediment transport potential (STP) index estimates a drainage system's relative capacity for transporting sediments deposited by slopes, riverbanks, or riverbeds. Sub-basins whose drainage system yields a low STP show reduced transport capacity, i.e. are susceptible to depositing sediments in rivers, therefore producing aggradation. On the other hand, sub-basins whose drainage system yields a high STP show greater capacity for discharging their sediment load in rivers flowing downstream.

The STP classification was grounded on the association of morphometric parameters of the drainage system for second-, third-, and fourth-order sub-basins in the area surveyed. According to Christofoletti (1980) and Zancopé & Bayer (2012), the association of morphometric parameters can only be performed among basins of a single hierarchical order. The selection of these orders stemmed from the reduced number of sub-basins under assessment which could cover a larger portion of the surveyed area. The morphometric parameters covered by the analysis are hydrographic density (Dh), drainage density (Dd), extension of surface route (Eps), and river gradient (Gd) for rivers forming the main axes of sub-basins involved. These parameters were calculated following Christofoletti's 1980 study.

To calculate and rank the drainage system's morphometric parameters, channels were vectorized with the use of satellite images. Digital Elevation Models (DEM), produced with SRTM images (30-metre resolution) made available by Nasa, yielded altimetric data. Images were georeferenced in WGS 1984 (UTM coordinate system, zone 23S). The analysis also included interpretation of vertical aerial photographs (scale 1:10.000), made available by Goiás state's Department of Environment and Water Resources.

Once reconstructed, the drainage system was ranked in accordance with Strahler (1952). Data and variables were processed by software ERSI®ArcGis 10.2, which made it possible to determine variables for calculating parameters. Scores of morphometric parameters for each sub-basin were ranked in five categories (very high, high, medium, low, and very low), following the automatic determination set by the Jenks Natural Breaks algorithm in ArcGis.

Parameters were associated in pairs, following three stages (Figure 2): parameters Dh and Dd were combined in stage 1, yielding a partial potential (partial 1); in stage 2, partial potential 1 was combined with Gd, yielding partial potential 2; in stage 3, partial potential 2 was combined with Eps, yielding the final STP.

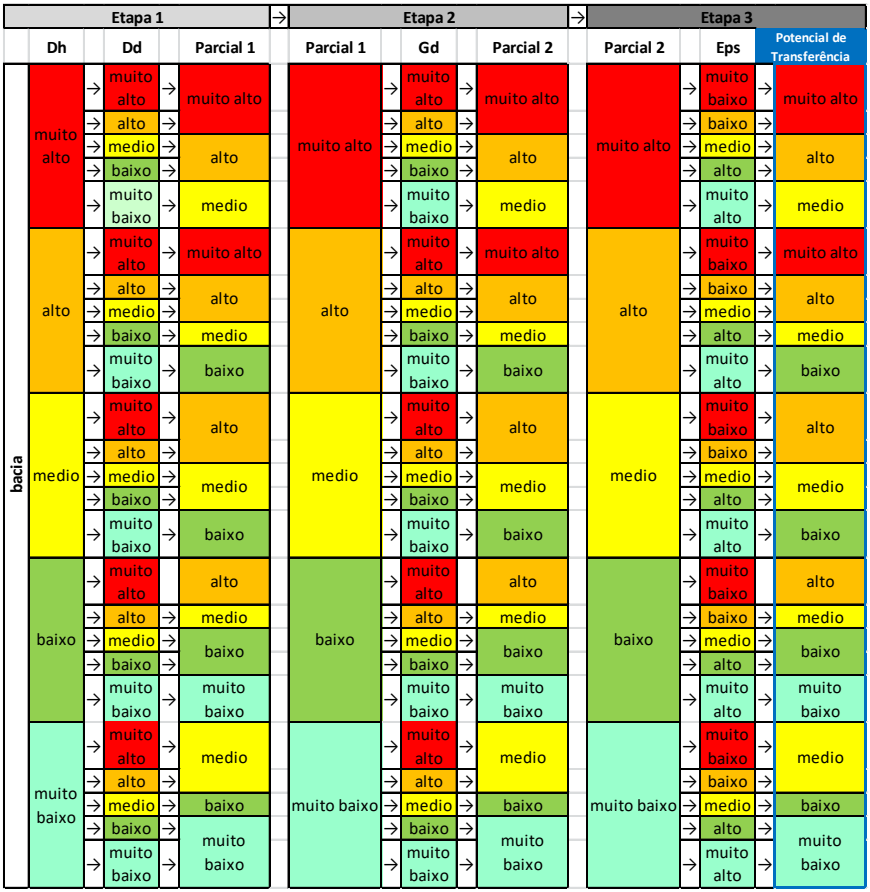


Figure 2. Associating stages of the drainage system's morphometric parameters for each sub-basin of a single hierarchical order.

Results and discussion

Data collection and the application of methodological procedures made it possible to assess the STP of second-, third-, and fourth-order sub-basins contributing to Terra Ronca's karst system. A total of 863 second-order sub-basins were identified over an area of 294.75 km², as well as 194 third-order sub-basins over an area of 562.54 km², and 37 fourth-order sub-basins over an area of 872.03 km².

STP of second-order sub-basins

Results show a predominance of sub-basins yielding low STP among second-order sub-basins. Given that the latter are mostly distributed over regions with a mainly flat relief, their Gd values are lower. Therefore, the association between the other morphometric parameters, in accordance with the selected methodology (Figure 2), yields a tendency for low STP.

Table 1 presents the number of sub-basins and their corresponding area for the three drainage basins of the surveyed area as regards STP. Figure 3 shows that the São Domingos river basin has a greater influence on the karst system due to its greater coverage and number of sub-basins.

Table 1. Number of second-order sub-basins and area size (km²) with regard to STP

	Very High	High	Medium	Low	Very Low	Total
Basins	Number/Area	Number/Area	Number/Area	Number/Area	Number/Area	Number/Area
São Domingos	0	6 / 2,95	221 / 62,38	258 / 85,11	65/ 15,69	550 / 116,14
São Vicente	0	1 / 0,43	40 / 14,35	55 / 27,38	13 / 19,11	109 / 61,28
São Mateus	0	1 /1,47	35 / 34,93	125 / 50,80	43 / 30,11	204 / 117,33
					Total	863 / 267,75

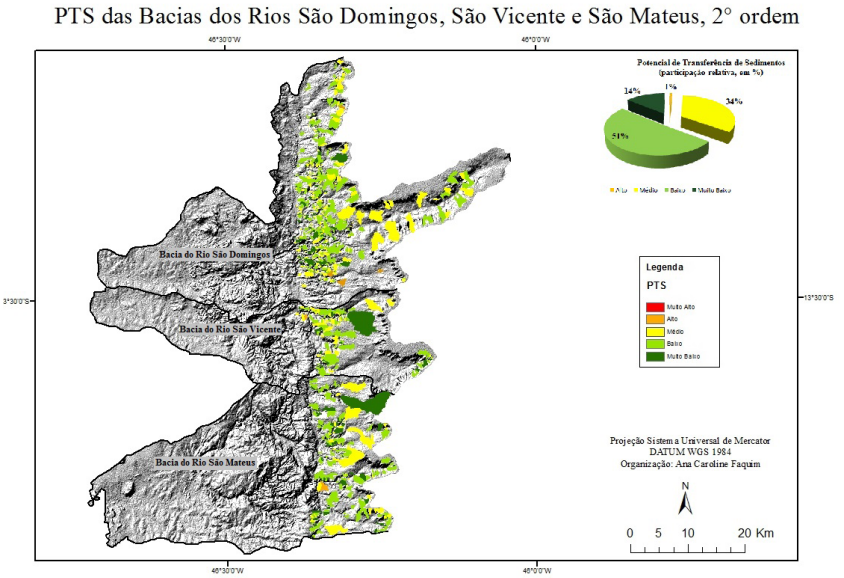


Figure 3. Sediment transport potential (STP) of São Domingos, São Vicente, and São Mateus river basins, second order.

STP of third-order sub-basins

Results show a predominance of third-order sub-basins with medium to high STP. Eight per cent of sub-basins have very high potential, 40% have high potential, 43% have medium potential, 8% have low potential, and only 1% have very low potential.

In terms of area size, sub-basins with low STP are larger than those with high STP. This occurs because the former are located in a mainly flat sector of the surveyed area (Figure 4), between the foot of Serra Geral de Goiás (to the east) and the karst terrain (to the west). Over this flat intermediary portion, sub-basins have larger areas than those with a high STP. On the other hand, the major rivers in sub-basins located over this flat portion have lower gradients and this, together with sub-basins' larger area size, help to reduce STP, given that these variables are used to determine the STP of each sub-basin. Correlations between morphometric variables, position in landscape partitioning, and lithology will be addressed by future research studies.

Table 2 shows the number of third-order sub-basins and their corresponding area for the three drainage basins of the surveyed area as regards STP.

Table 2. Number of third-order sub-basins and area size (km²) with regard to STP

	Very High	High	Medium	Low	Very Low	Total
Basins	Number/Area	Number/Area	Number/Area	Number/Area	Number/Area	Number/Area
São Domingos	13 / 2,47	61 / 40,12	49 / 130,44	8 / 78,90	1 / 12,83	132/ 264,31
São Vicente	0	6 / 5,52	16/29,91	3/62,12	0	25/97,57
São Mateus	2/0,82	11/ 6,37	18 /97,43	5/62,96	1/32,95	37/200,56
					Total	194/562,54

The general trend i.e. the greater number of sub-basins with medium or high STP over the entire area surveyed was also verified for each of the three drainage basins under analysis (São Domingos, São Vicente, and São Mateus). Special attention should be given to the São Domingos basin, which yielded more sub-basins with high STP than the other two. This difference probably stems from variables used to determine certain morphometric parameters e.g. sub-basin area size and gradient of major rivers.

The distribution of these variables over the surveyed area influences the location of sub-basins with high STP in the São Domingos and São Vicente basins; the highest frequency was recorded closer to portions with outcrops of the Bambuí Group and of the karst system. Such distribution among high STPs fails to occur in the São Mateus basin.

The gradient of major rivers seems to be an important variable in determining STP in the surveyed area, given that sub-basins with high STP were also registered on the slopes of Serra Geral de Goiás. The correlation between morphometric variables (gradient, basin area, number of channels, etc.) lies outside the scope of this study and therefore will not be addressed at present.

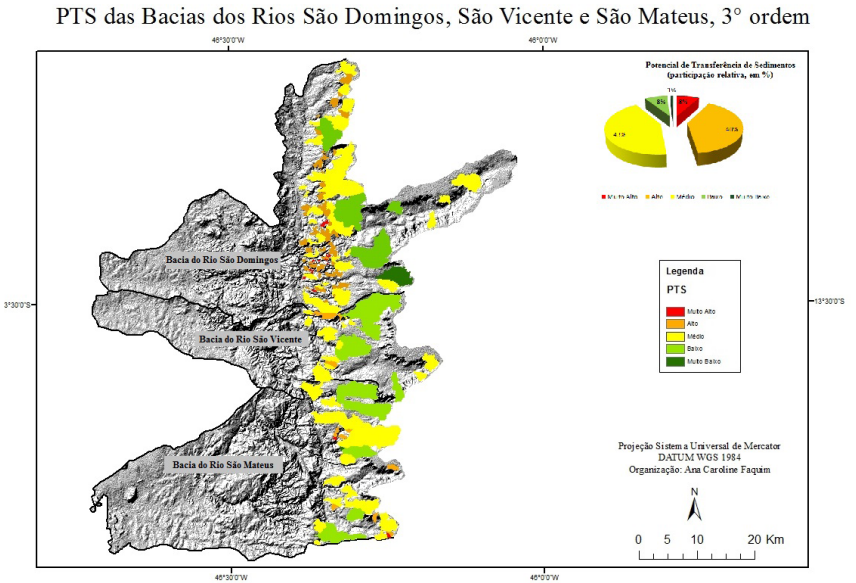


Figure 4. Sediment transport potential (STP) of São Domingos, São Vicente, and São Mateus river basins, third order.

STP of fourth-order sub-basins

There are 37 fourth-order sub-basins in the São Domingos, São Vicente, and São Mateus rivers, stretching over an area of 872.03 km². Six per cent of sub-basins have a very high STP, 24% have a high STP, 43% have a medium STP, and 27% have a very low STP.

The São Domingos river basin has two sub-basins with a very high STP; this stems from their large area size, type of relief and rock formation, as well as river gradient. Drainage density, which associates the length of all channels with area size, is also a major factor in determining the behaviour of river channels – in this case, a strong capacity to transport sediments beyond the occurrence registered on the slopes of Serra Geral de Goiás.

Table 3 shows the number of sub-basins and their corresponding area for the three drainage basins of the surveyed area as regards STP.

Table 3. Number of fourth-order sub-basins and area size (km²) with regard to STP

	Very High	High	Medium	Low	Very Low	Total
Basins	Number/Area	Number/Area	Number/Area	Number/ Area	Number/Area	Number/ Area
São Domingos	2 / 235,45	3 / 22,05	10 / 107,30	6 / 86,43	0	21 / 451,24
São Vicente	0	2 / 123,65	3 / 79,49	0	0	5 / 203,14
São Mateus	0	4 / 42,29	3 / 109,49	4 / 73,87	0	11 / 225,65
					Total	37 / 872,03

In general, fourth-order sub-basins have a greater capacity for sediment transport, hence reducing particle deposition.

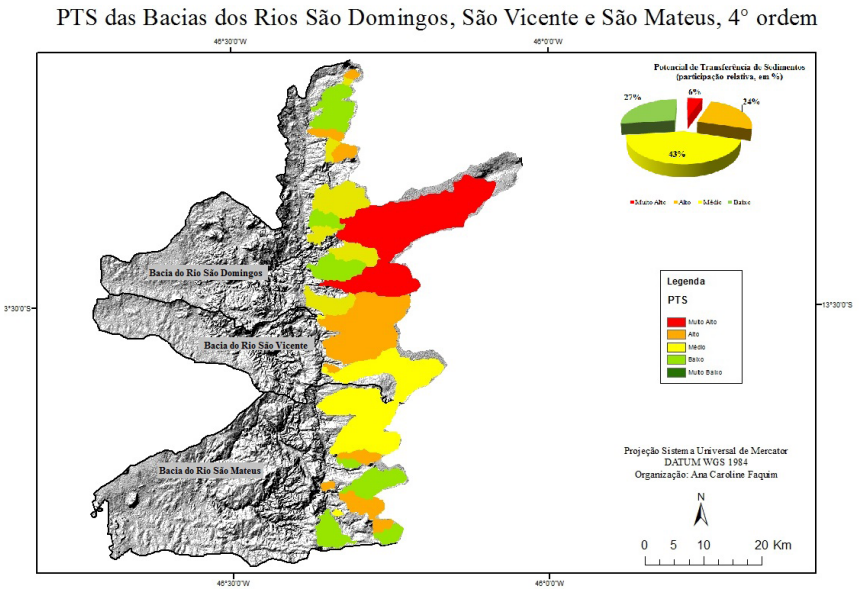


Figure 5. STP of São Domingos, São Vicente, and São Mateus river basins, fourth order.

Comparison of hierarchical orders

Figure 6 offers a comparison of the hierarchical orders under analysis. The surveyed area revealed 17 sub-basins with very high STP, 95 with high STP, 395 with medium STP, 464 with low STP, and 123 with very low STP.

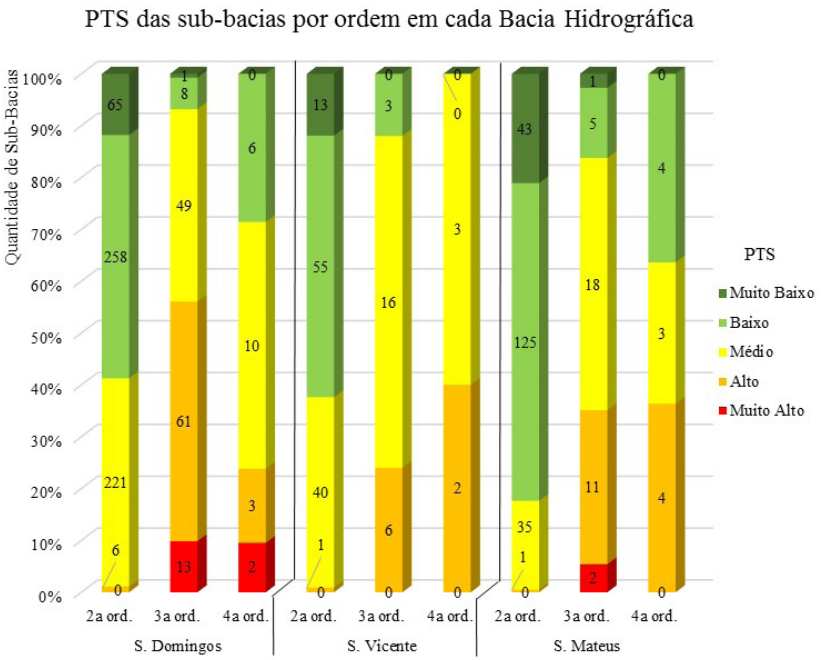


Figure 6. Comparison of STP values of sub-basins of different orders in each of the three drainage basins.

The comparison of STP values among different orders indicates that third-order sub-basins yield higher scores than the others, whereas second-order sub-basins show a tendency for medium scores.

As shown by Figure 6, STP varies from medium to low for all three drainage basins (São Domingos, São Vicente, and São Mateus). However, the São Domingos river basin yields more sub-basins with very high STP than the other two, but its capacity for sediment transport is generally medium to low; a similar trend was observed for the São Mateus river basin.

STP and caves

Seven caves in the surveyed area were selected for the present study; they consist of sinkholes located in the upper portion of São Mateus, São Vicente, and São Domingos river basins. Three of these caves are

located in the São Vicente basin and four in the São Mateus basin. Figure 7 shows the number of sub-basins (whose drainage system flows into each registered cave) and respective STP values yielded by the analysis.

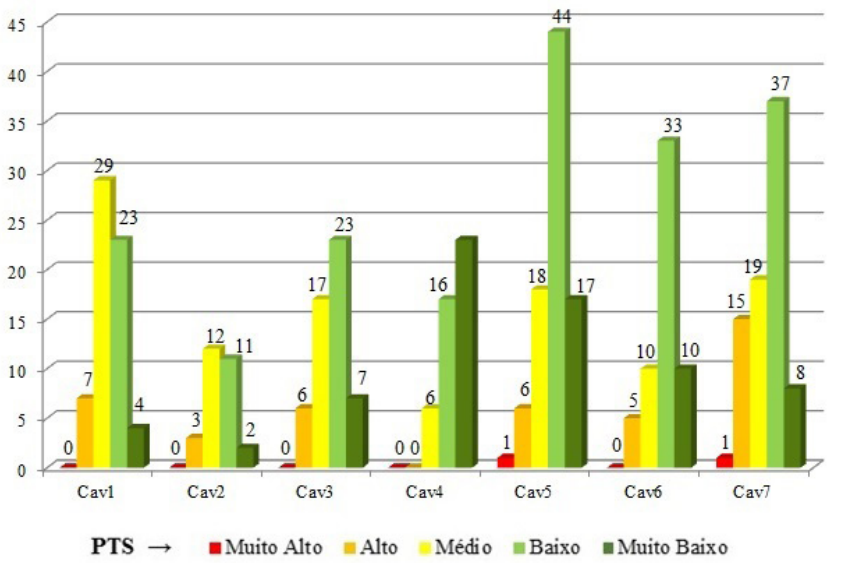


Figure 7. Number of sub-basins (and respective STP values) which flow into TRSP caves. Cav1 – Cave of Angélica creek; Cav2 – Cave of Bezerra brook; Cav3 – Cave of São Vicente river; Cav4 – Cave of São Mateus river; Cav5 – Cave of Lapa river (Terra Ronca); Cav6 – Cave of Palmeiras creek; Cav7 – Cave of São Bernardo river.

The drainage system of São Bernardo river cave (Cav7), part of the drainage basin of the São Mateus river, yielded the highest number of sub-basins with high STP values; it was followed by the Terra Ronca cave (Cav5) from the same river basin (Figure 8). The remaining caves ranked as follows, in descending order of sub-basins with high STP values: Bezerra (Cav2), Angélica (Cav1), Palmeiras (Cav6), and São Mateus (Cav4).

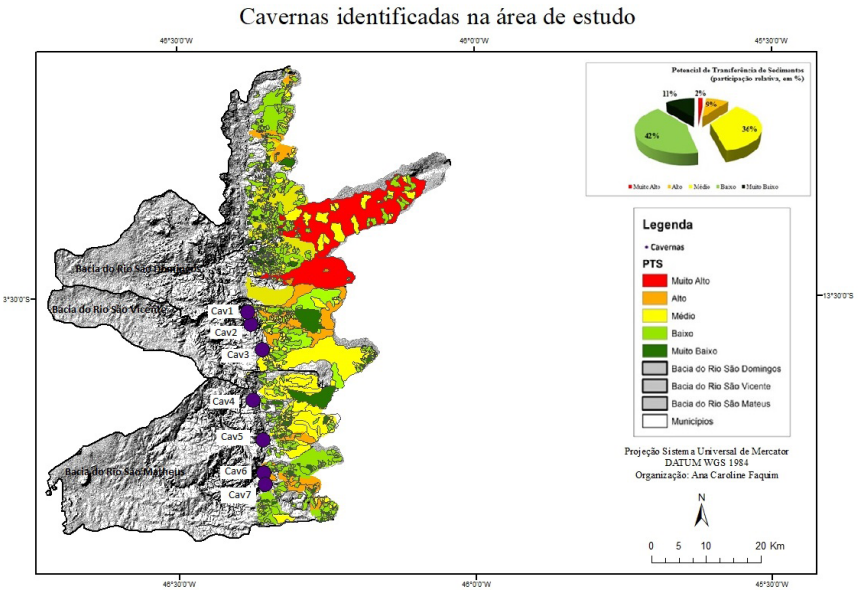


Figure 8. Location of caves found in the surveyed area. Cav1 – Cave of Angélica creek; Cav2 – Cave of Bezerra brook; Cav3 – Cave of São Vicente river; Cav4 – Cave of São Mateus river; Cav5 – Cave of Lapa river (Terra Ronca); Cav6 – Cave of Palmeiras creek; Cav7 – Cave of São Bernardo river.

Conclusion

The upper portion of the drainage systems of São Domingos, São Vicente, and São Mateus rivers showed a predominantly medium STP, both in terms of relative area and of number of contributing sub-basins. These values suggest that sub-basins' drainage systems have a moderate capacity for depositing their sediment loads on TRSP caves.

Second-order sub-basins recorded mostly low STP values, which highlights their relative deficiency in sediment transport. Third-order sub-basins, in turn, yielded the highest number of high STP values, particularly the São Domingos basin, located to the north of the surveyed area, followed by the São Mateus basin. Fourth-order sub-basins yielded mostly medium to high STP values, again especially with regard to the São Domingos and São Mateus basins.

These results suggest that second-order sub-basins, despite their proximity to rivers' headwaters on the slopes of Serra Geral de Goiás, lose transport capacity as their drainage system crosses the flat terraces embedded at the foot of the mountain. Hierarchical order, hydrographic density, and river gradient increase as the drainage system flows closer to karst terrain, thus indicating greater relief dissection and increasing STP.

Among the caves selected for this study, the São Bernardo river cave (Cav7) shows greater sediment transport potential, in that it constitutes the river mouth of the drainage system with the highest number of sub-basins with high STP values. Following, in descending order of STP scores, are Terra Ronca (Cav5), Bezerra (Cav2), Angélica (Cav1), Palmeiras (Cav6), and São Mateus (Cav4) caves.

It must be pointed out that the largest part of the São Mateus river basin lies outside the park's integral protection zone as well as houses the São Bernardo (Cav6) cave, which yielded the highest number of sub-basins with high STP. Therefore, special attention should be given to the use, occupation, and agricultural/cattle-raising management of both this basin and the western border of Bahia state's plateaus, located close to the Serra Geral de Goiás.

The results of the present study demonstrate the potential capacity for sediment transport shown by the drainage system in the surveyed area. In addition to the drainage system's properties, effective sediment transport is dependent on natural features of drainage basins (soil, relief, etc.) as well as on land use and occupation (vegetation remnants, management, land situation, etc.). Hence further research is needed concerning the drainage basins in the area surveyed, focusing on an integrated analysis of all factors and variables involved, in addition to monitoring the sediment load deposited in TRSP's karst system.

Acknowledgements

The authors wish to thank the Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq) for financially supporting this research project (Edital Universal MCTI-CNPq no. 14/2014; process no. 461869/2014-4; period: 19 November 2014–31 November 2017) and Universidade Federal de Goiás (UFG) for granting a scholarship linked to the Scientific Initiation Institutional Program;

both these sources of support enabled this research to be carried out. The authors also wish to acknowledge the Management Department for Environmental Compensation and Protected Areas, subordinated to Goiás state's Department of Enviroment, Water Resources, Infrastructure, Cities, and Metropolitan Affairs, for granting permission for this research to be carried out inside the Terra Ronca State Park.

References

BARRELLA, W. et al. As relações entre as matas ciliares os rios e os peixes. In: RODRIGUES, R. R.; LEITÃO FILHO; H. F. (Ed.). *Matas ciliares*: conservação e recuperação. 2. ed. São Paulo: Editora da Universidade de São Paulo, 2001.

BRASIL. Ministério das Minas e Energia. *Projeto radambrasil*: levantamento de recursos naturais, Folha SD 23 Brasília. Rio de Janeiro, 1982. v. 29. (6 mapas: geologia, geomorfologia, pedologia, vegetação, uso potencial da terra, avaliação do relevo).

CHRISTOFOLETTI, A. *Geomorfologia*. 2. ed. São Paulo: Edgard Blücher, 1980.

CPRM. Companhia de Pesquisa de Recursos Minerais. *Projeto Rede Integrada de Monitoramento das Águas Subterrâneas*: relatório diagnóstico Sistema Aquífero Urucuia Bacia Sedimentar Sanfranciscana. Belo Horizonte: CPRM – Serviço Geológico do Brasil, 2012. (Volume 10).

LATRUBESSE, E. M.; CARVALHO T. M. *Geomorfologia do Estado de Goiás e Distrito Federal*. Goiânia: Superintendência de Geologia e Mineração do Est. de Goiás, 2006. (Série Geologia e Mineração, n. 2).

LAUREANO, F. V. et al. Two million of river and cave aggradation in NE Brazil: implications for speleogenesis and landscape evolution. *Geomorphology*, v. 273, p. 63-77, 2016.

MATEUCCI, M. B.; SOARES FILHO, J. N.; NASCIMENTO, E. P. Mapa e roteiro ecoturístico do complexo de cavernas do Parque Estadual Terra Ronca – PETeR. In: INTERNATIONAL CONGRESS OF SPELEOLOGY, 13. Brasília, 2001. *Anais...* Brasília: UIS, SBE, 2001. p. 689-694.

MELIANI, P. F. Mapeamento da rede hidrográfica e análise dos parâmetros da densidade de drenagem aplicados ao estudo ambiental: o caso da Bacia do Rio Jeribucassu, Itacaré, Bahia. *Geografia*, Rio Claro, v. 31, n. 1, p. 119-136, jan./abr. 2006.

STRAHLER, A. N. Hypsometric (area-altitude) analysis of erosional topography. *The Geological Society of America Bulletin*, v. 63, p. 1117-1142, 1952.

ZANCOPÉ, M. H. C.; BAYER, M. Proposta metodológica para avaliar o potencial de transferência de sedimentos de bacias hidrográficas a partir de índices morfométricos. In: SIMPÓSIO NACIONAL DE GEOMORFOLOGIA, 9, Rio de Janeiro, 2012, *Anais*....Rio de Janeiro: UFRJ/UGB, 2012. p. 1-3.

_____; GONÇALVES, P. E.; BAYER, M. Potencial de transferência de sedimentos e suscetibilidade a assoreamentos da rede hidrográfica do alto Rio Araguaia. *Boletim Goiano de Geografia*, Goiânia, v. 35, n. 1, p. 115-152, jan./abr. 2015.

_____; MOMOLI, R. S.; BAYER, M. *Movimentos de massa nas nascentes do Rio São Vicente, Parque Estadual "Terra Ronca"*. Goiânia: LABOGEF, 2013. (Estudo técnico – Ofício SUCON; Secretaria do Meio Ambiente e Recursos Hídricos do Estado de Goiás).

Received for publication on 01 July 2017
Accepted for publication 09 August 2017