http://lsie.unb.br/ugb/
ISSN 2236-5664

Revista Brasileira de Geomorfologia

v. 22, nº 3 (2021)

http://dx.doi.org/10.20502/rbg.v22i3.1980

Artigo de Pesquisa

Automated analysis of landforms of the Paraguaçu River Basin / Bahia

Análise automatizada do relevo da Bacia do Rio Paraguaçu / Bahia

Ludimila de Oliveira de Amorim [1], Luís Eduardo de Souza Robaina [2] e Romario Trentin [3]

[1] Universidade Federal do Rio Grande do Sul, Programa de Pós-Graduação em Geografia, Porto Alegre, Brasil. E-mail: ludimilaamorim@hotmail.com
ORCID: https://orcid.org/0000-0002-2642-2629

[2] Universidade Federal de Santa Maria, Departamento de Geociências, Santa Maria, Brasil. E-mail: lesrobaina@yahoo.com
ORCID: https://orcid.org/0000-0002-2390-6417

[3] Universidade Federal de Santa Maria, Departamento de Geociências, Santa Maria, Brasil. E-mail: romario.trentin@gmail.com
ORCID: https://orcid.org/0000-0002-0615-2801

Recebido: 04/07/2020; Aceito: 19/01/2021; Publicado: 01/07/2021

Resumo: A morfologia do relevo é o resultado da ação das forças tectônicas e dos agentes da superfície terrestre que ao longo do tempo desenvolvem formas diferentes. O geoprocessamento e o SIG permitem aplicar uma proposta de classificação do relevo adaptada para o ambiente informatizado. O objetivo do trabalho é analisar o relevo da bacia hidrográfica do rio Paraguaçu, no estado da Bahia. O relevo foi caracterizado em ambiente computacional quanto às altitudes, amplitudes e declividades e os elementos de relevo foram caracterizados por meio do intercruzamento entre as litologias, altitudes e formas do relevo. Foram definidas dez unidades de relevo com base nas respectivas morfologias e morfometrias. Conclui-se que a bacia possui uma assimetria importante associada à distribuição dos afluentes do rio principal.

Palavras-chave: Geomorfologia; Geomorfometria; Cartografia; Geomorphons

Abstract: The morphology of the relief is the result of the action of tectonic forces and agents of the Earth's surface that over time develop different forms. Geoprocessing and GIS allow apply a proposal for classification of landforms adapted to the computerized environment. The aim of this work was the analysis of the landforms of the Paraguaçu river basin in the state of Bahia, Brazil. The landforms was characterized in a computational environment by altitudes, amplitudes and declivity of slopes and the landform elements, was based on a crossing of lithological information, altimetric data and analysis. It was determined ten landforms units based on the respectively morphological and morphometric of the relief. In conclusion, the basin has an important asymmetry in the distribution of the tributaries of the main river.

Keywords: Geomorphology; Geomorphometry ; Cartography; Geomorphons

1. Introduction

The spatial arrangement of homogeneous landforms, landform elements and slopes shape are the result of the action of the tectonic forces, that provokes uplifts and relegation, and agents of the terrestrial surface that act in the rocky materials decomposing and disaggregating that over time develop different features and forms.

The development of geoprocessing methods mainly GIS makes it's possible to represent the terrestrial surface as digital models (DEM). Which allow the topographic analysis of a zone of interest, as well as the automated calculation of a series of related variable measurements using equations applied to numeric models of altimetric representation (WILSON; GALLANT, 2000; VIDAL-TORRADO; LEPSH; CASTRO, 2005; MUÑOZ, 2009; WILSON, 2012).

Macmillan e Shary (2009) emphasize that all methods of automatic prediction of classes of geomorphic spatial entities are based on the creation of rules for the establishment of predictive relations between the input variables and the resulting classes. Iwahashi e Pike (2007) do automated classifications of topography from DEMs by an unsupervised nested-means algorithm. Most of the existing methods of automated classification of the earth's structure have their roots in differential geometry. The existing approaches focus on the best way to use the information contained in the geomorphometric variables and in the choice of the target units of classification (LIAO, 2010).

The present work aims to analyze the landforms, landform elements and lithologies in an automated way, combining different morphometric elements to compartmentalize the relief in the Paraguaçu River basin.

Bolongaro-Crevenna, et al. (2005) did geomorphometric analysis for characterizing landforms in Morelos, Mexico. For landform classification Minár e Evans (2008) used elementary forms for land surface by terrain analysis and geomorphological mapping. Minatel Tinós et al. (2014) implemented a methodology adapted to the digital environment. The authors considered for the classification the slope, amplitude and profile, which were calculated through movable windows and added together to generate a map of landforms. The landforms of the Paraná state (SILVEIRA; SILVEIRA, 2015) were defined from the automated crossing of slope declivity and height. Pineda et al. (2017) apply a geomorphological classification parameterized from the digital elevation model (DEM) and topographic attributes to the mapping of the landforms and slopes in the basin of the river Neverí, Venezuela.

The analysis of the landform elements was carried out by Seijmonsbergen et al. (2011) developing extraction of geomorphological features using DEMs. Gerente Valeriano e Moreira (2018) used a new methodology to classify the relief patterns of the Itajaí-Açu river basin, in the state of Santa Catarina by means of regional analysis of geomorphometric data, using DEM. Trentin et al (2016) and Silveira et al. (2017) used the Topographic Position Index (IPT). Jasiewicz e Stepinski (2013) established a classification called geomorphons made an analogy between the textural classification of an image, based on the gray-scale spatial arrangement, comparing it with the specified distribution of the elevation values of the DEM for a given region. Robaina, Trentin e Laurent (2016) applied this proposal in the Rio Grande do Sul and Silveira (2018) to the Paraná state to define the distribution and relationship between the relief elements in the geomorphological compartments.

2. Study Area

The Paraguaçu River Basin (Figure 1) is located in the central-eastern region of the state of Bahia, geographically limited by the coordinates 11 ° 00 'S and 14' 00 ° S and 38 ° 00'W and 42 ° 00 'W.

Considered as the most important river system with entirely state domain, draining an area of 54,877 km², where about 10.14% are located in the Bahian territory, corresponding to 86 municipalities (INEMA- INSTITUTO DO MEIO AMBIENTE E RECURSOS HÍDRICOS, 2014).

According to INEMA (2020) there are 94 dams of varying sizes and functionality in the basin, and the Paraguaçu River is also responsible for 60% of the supply of the capital of Bahia, Salvador.

Based on Köppen's climatic classification, the river basin area is dominated by three types of climate and their variations: (1) the tropical altitude climate in the highest part of the basin, corresponding to the Chapada Diamantina region; (2) the dry climate in the western part, corresponding to the middle section of the basin; and (3) the rainy tropical climate in the lower course of the basin, close to the coast (SEI- SUPERINTENDÊNCIA DE ESTUDOS ECONÔMICOS E SOCIAIS DA BAHIA, 1997).

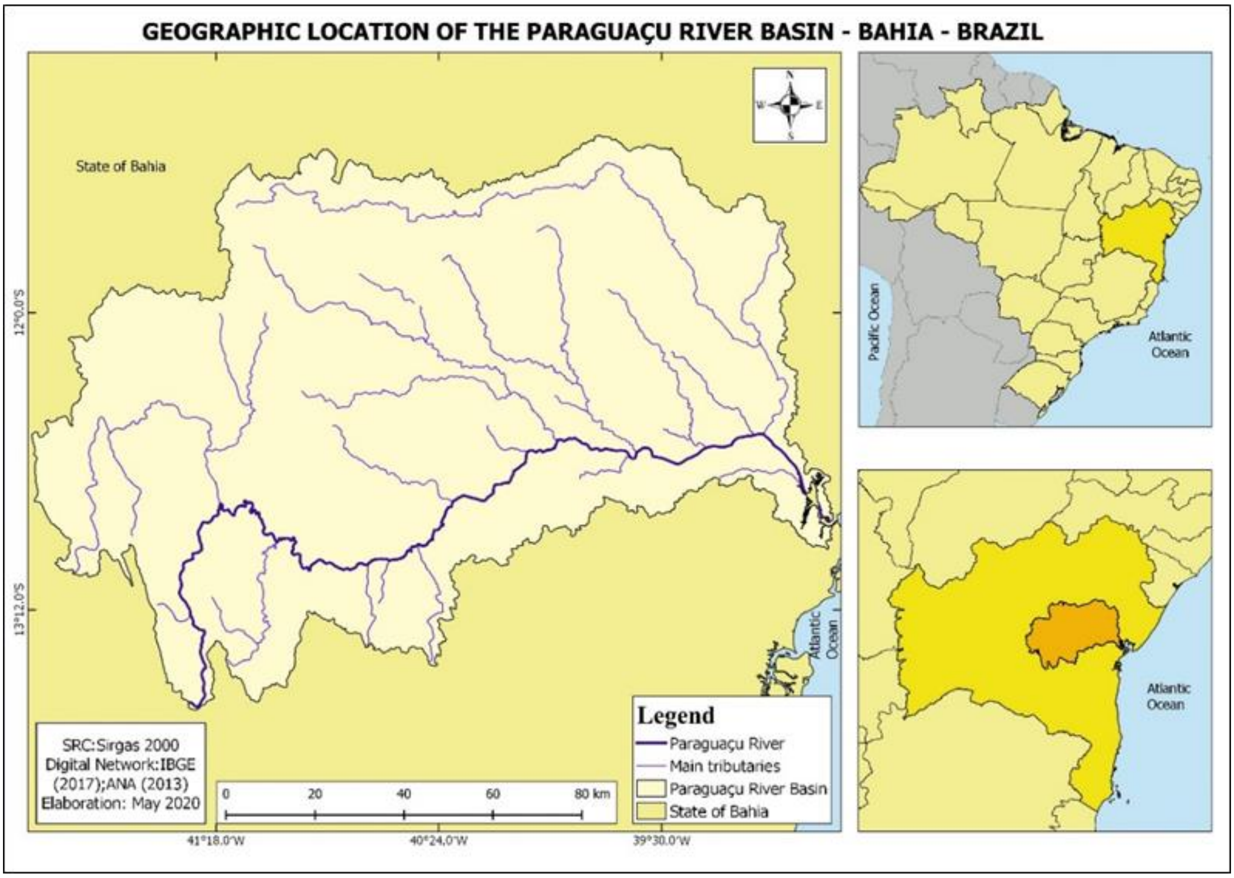

Figure 1. Geographic location of the Paraguaçu River Basin

3. Methodology

The Paraguaçu River basin had its digital relief parameters, mapped and quantified with the GIS and the cartographic base consisting in data from codified hydrographic basins of (ANA - AGÊNCIA NACIONAL DE ÁGUAS, 2018), for spatial delimitation and definition of the rivers that constitute the basin.

It was carried out an analysis of morphometric parameters related to the hydrographic network and the Digital Elevation Model (DEM) from the Shuttle Radar Topography Mission (SRTM) (KRETSCH, 2000) with spatial resolution of 3 arc-second (90 meters). Even though the availability of DEM for better spatial resolutions, we opted for 3 arc-seconds data (approximately 90 meters), due to the better noise level, especially in the flat areas, which are significant in the study area.

Digital processing as well as the database was organized and managed with ArcGIS 10.3®, by spatial analysis and three-dimensional analysis tools. The hydrographic hierarchy of the channels net stands out, where the watercourses was classified and quantified according the proposal of Strahler (1952).

The relief was characterized by the altitudes and amplitudes present of the basin and the its declivity, according to the classes proposed by Ponçano et al. (1981) and adapted by Trentin and Robaina (2005) (Table 1). The amplitudes are defined using the Focal Statistics tool that analyzes the difference in altitude in a circular mobile window with a two pixel radius and the declivity is calculated in percentage using the Slope tool that defines the slope between the pixels in a 3x3 pixel moving window over the DEM.

Table 1. Classification of the landforms adapted from (PONÇANO et al., 1981)

Altimetric amplitude	Declivity	Landforms
< 100 meters	**< 2%**	**Flat Areas**
	2 – 5%	**Slightly undulations hills**
	5 a 15%	**Undulating hills**
	> 15%	**Large hills and buttes**
> 100 meters	**> 15%**	

For the determination of the relief elements the proceeding is based on the proposal of Jasiewicz e Stepinski (2013) characterizing the difference between topographic height, distance and the angle of direction of the neighboring points in relation to the central cell (zenith and nadir angles). Ojala, Pietikäinen e Mäenpää (2002) introduced local binary patterns (LBP) (Local Binary Patterns) as texture descriptors. The LBP is built from a local 3 × 3 neighborhood over a central cell. Liao (2010) extended the LBP to standards of three values, defined as 1 if its value exceeds the value of the central cell by at least t where t is a specific threshold value. A neighbor is labeled -1 if its value is at t less than the value of the central cell, otherwise, the neighbor is labeled 0, as it has not exceeded the value of t.

Jasiewicz e Stepinski (2013) to perform the processing of the DEM and the generation of the geomorphons, the online application was made available at the electronic address << http://sil.uc.edu/geom/app >>. The application code is also available for download at on http://sil.uc.edu/, and which can be implemented in the SAGA software environment. The application requires a set of raster data and two scalar values as parameters. The input file for the scan is a DEM and the two parameters are lookup L (distance in meters or cell units) and threshold (leveling in degrees). For the free parameters, an L value equal to 20 pixels (1800 meters) and degrees t equal to 2º was applied.

The final product representing a cross of lithological information, altimetric data and analysis of relief shapes and elements determined by the landforms units of the river basin (Figure 2).

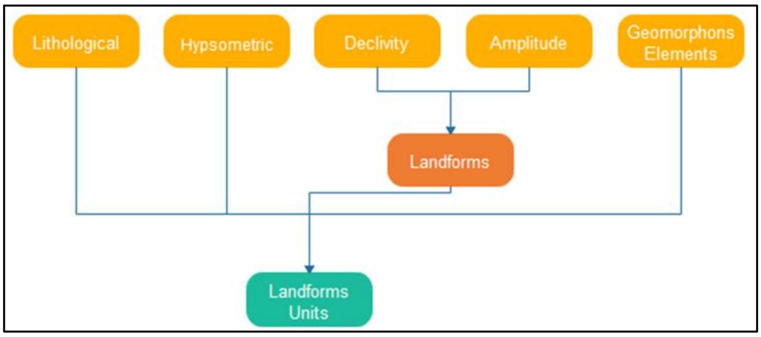

Figure 2. Flowchart showing the layers of information used to define the Landforms Units.

4. Results

The fluvial hierarchy of the drainage network of the Paraguaçu river basin (Figure 3), carried out on the hydrographic map in the scale 1: 50,000, is classified as 5th order with an extension of the 128.77km. The basin has an important asymmetry in the distribution of the tributaries in relation to the main river, not only in relation to their extension, but also in terms of density.

The left bank receives the Santo Antônio, Piranhas, Capivari, do Peixe, Paratigi, Saracura, Paulista, Preto, Bonito, Utinga, Cochó, Jacuípe, Tupim and Curimataí rivers, among others, of smaller size. While on the right bank, only the rivers of Una, Palma, Cambuca and the São Francisco, Vermelho, Roncador, Toca da Onça, Grande and Sebastião streams and other smaller tributaries. The Capivari, Peixe and Jacuípe rivers, all on the left bank, are 4th order channels.

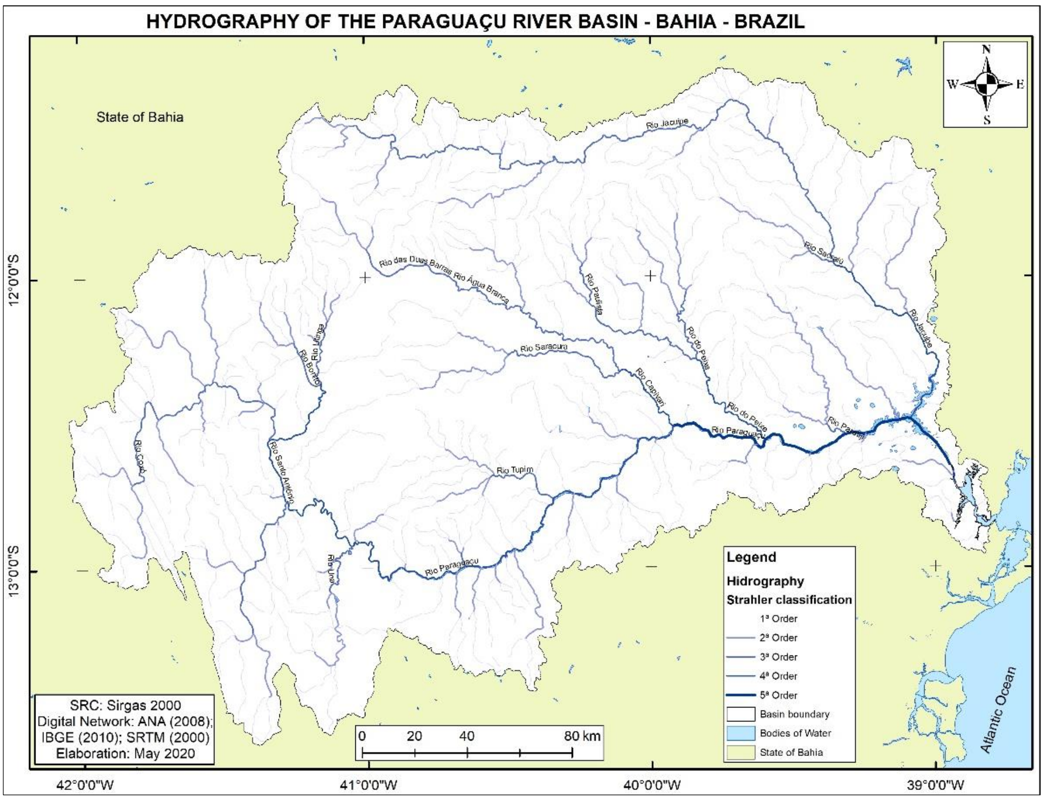

Figure 3. Hidrographic Map of the Paraguaçu river Basin

According to Souza, Melo e Kosin (2003), the Tectonics Domains in Paraguaçu river basin are represented in (Figure 4). The geomorphologically compartments are represented in the (Figure 5) as reported by IBGE (2010).

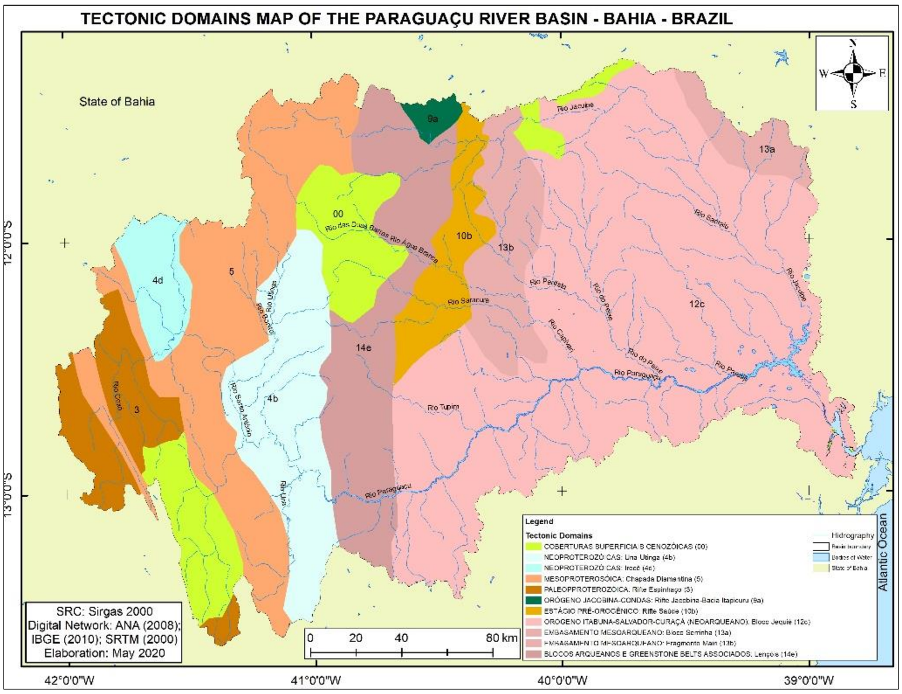

Figure 4. Tectonic Domains Map of the Paraguaçu river Basin

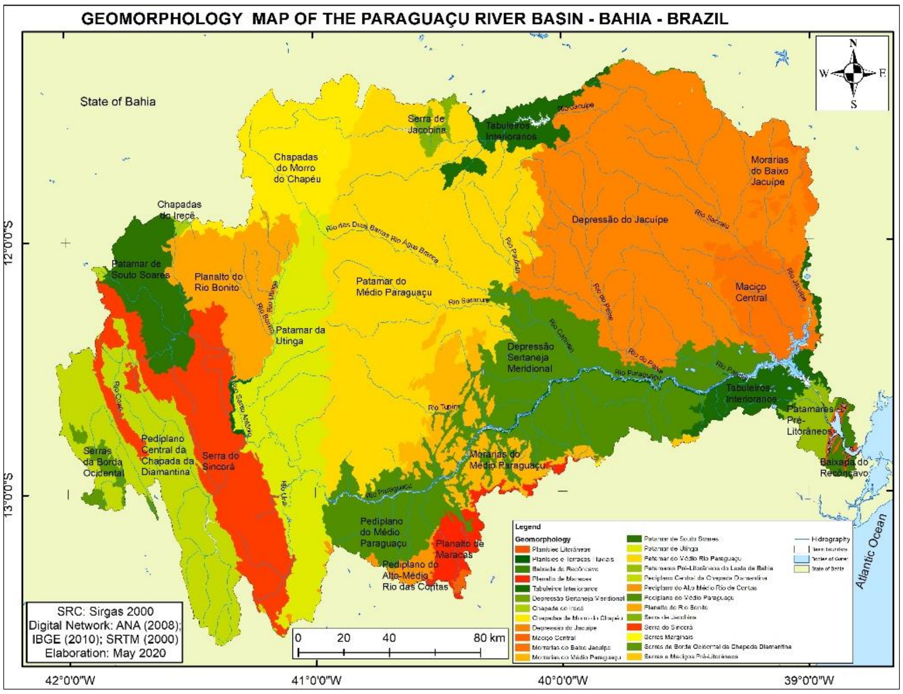

Figure 5. Geomorphology Map of the Paraguaçu river Basin

The analysis of the relief in the basin was determined the variation in altitude, the landforms (Figure 6) and the geomorphons elements (Figure 7).

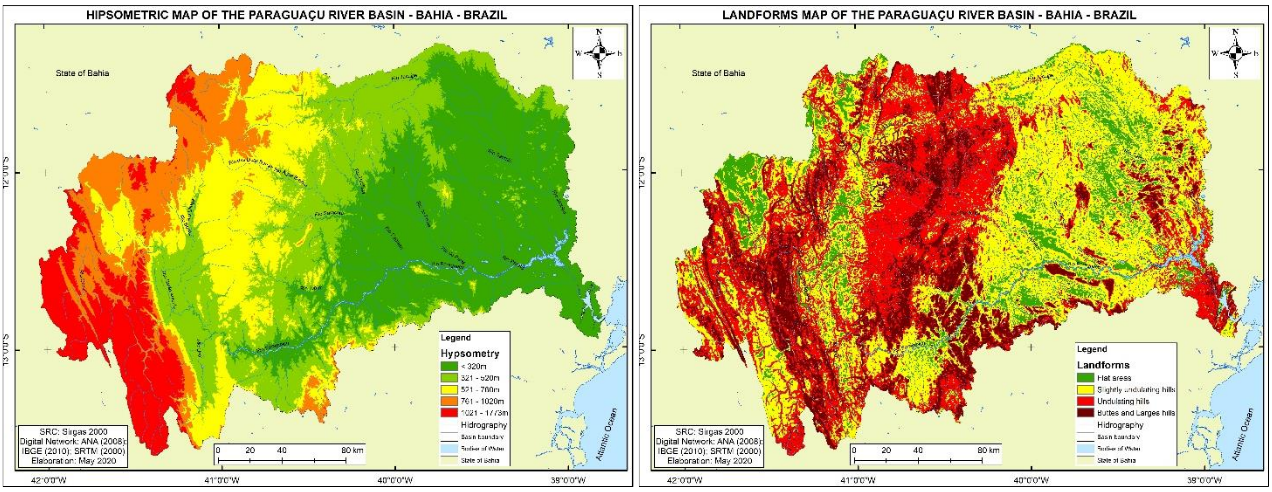

Figure 6. Hipsometric and Landforms Maps of the Paraguaçu river Basin

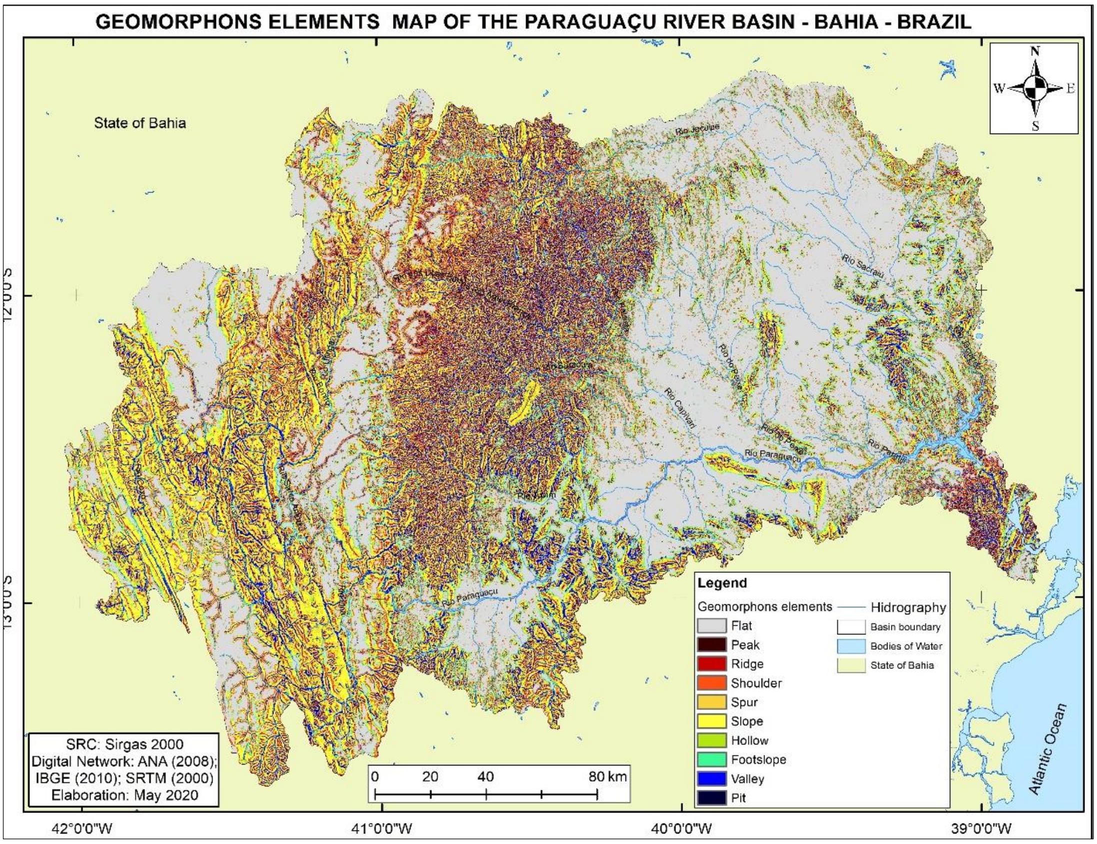

Figure 7. Geomorphons elements Map of the Paraguaçu river Basin

The information and data of lithological and morphological was evaluated allowed to determine 10 Landforms Units (Figure 8) and (Table 2). Some of the main landforms units that make up the landscapes of the Paraguaçu River basin, are represent in (Figure 9).

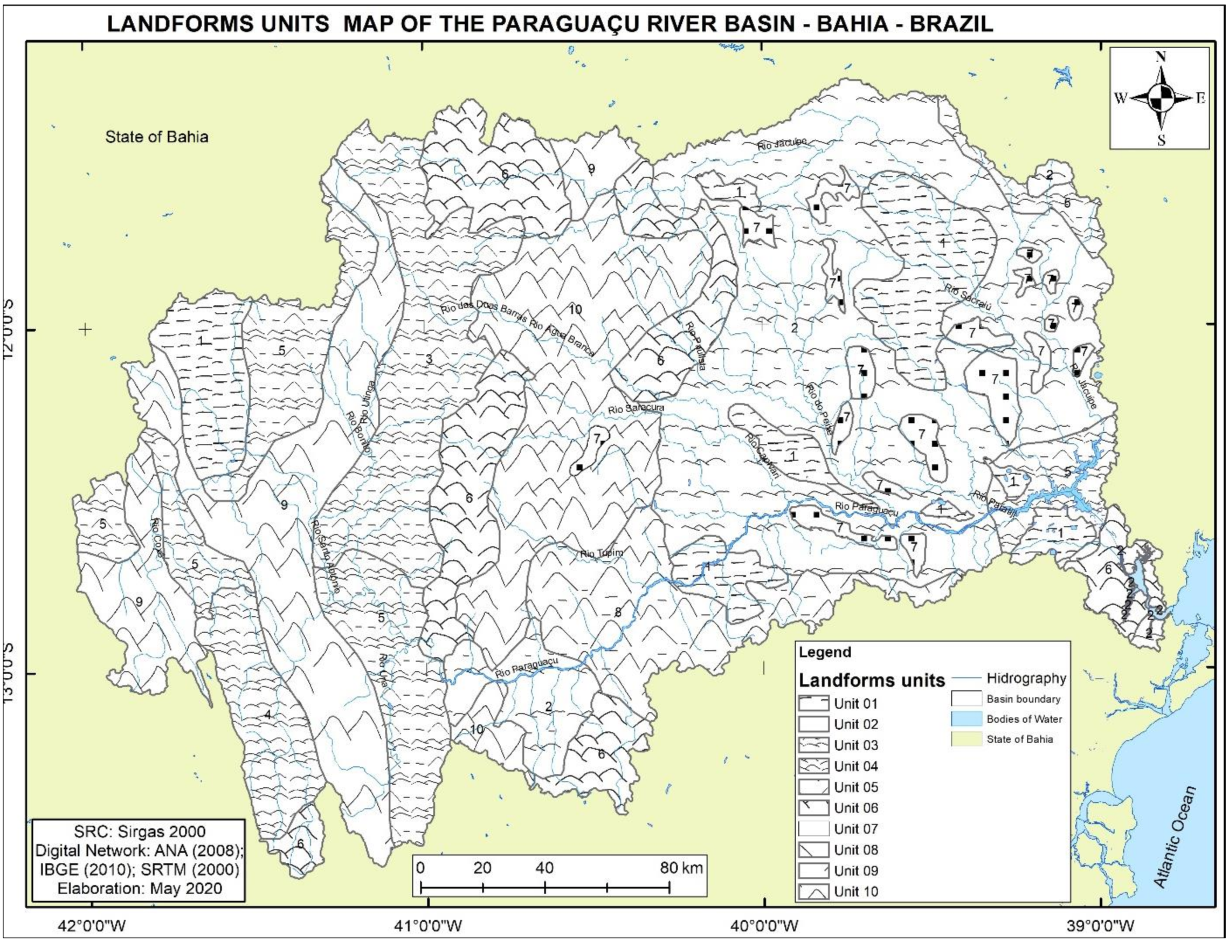

Figure 8. Landforms Units Map of the Paraguaçu river Basin

Table 2. Quantification of the landforms units

Landforms Units	Area km²	Porcentage
Unit 01	4,719.31	8.59
Unit 02	14,197.61	25.85
Unit 03	4,105.95	7.48
Unit 04	1,601.99	2.92
Unit 05	6,228.64	11.34
Unit 06	5,996.59	10.92
Unit 07	1,702.57	3.10
Unit 08	3,111.04	5.66
Unit 09	7,085.94	12.90
Unit 10	6,173.11	11.24

Figure 9. A) Sincorá Saw. Unit 9. Source: Augusto J. Pedreira. B) Iaçu city. Unit 8. Located between the Sertaneja Depression and the Hills of Middle Paraguaçu. Source: LK Comunicações. C) Pedra do Cavalo Dam. Flooded areas are the units 5 and 1. Country Tray. Source: Carlos Augusto. D) Orobó Saw. Ruy Barbosa city. Unit 10. Source: Junior Queiroz. E) Itatim city. Unit 2 and 7. Sertaneja Depression. Source: Geraldo Marcelo Lima. F) Cities of Cachoeira and São Félix, low course of the Paraguaçu river. Unit 6. Pre-Coastal Trays. Source: Carlos Augusto. G) Morro do Chapéu Plateau. It constitutes units 3,5,6 and 9. Source: Rogério Ruschel. H) Unit 1. Souto Soares Landing. Source: Government of the State of Bahia. I) Íguape Bay. Units 1 and 5. Source: Carlos Augusto.

The region of the upper course of the Paraguaçu River is geomorphologically represented by the Chapada Diamantina, which is made up of a block controlled by folds and faults with altitudes above 700 meters and in some places surpassing more than 1500 meters of altitude in the busiest relief.

Section the highest altitudes of the Chapada Diamantina within the Paraguaçu River basin occur in the West / Southwest in the geomorphological region of the Central Pediplane (Pediplano Central), with landforms developed by Meso / Paleoproterozoic metarenites and metasiltites. These rocks constitute the tectonic Domain of the Espinhaço Rift, which represents a rift-sag-type basin that exhibits a rift phase followed by a flexural phase due to the change in the subsidence regime from mechanical to thermal, without evolving to a passive margin with the development of oceanic scattering centers (Allen e Allen 1990). The landforms and the organization of the drainage network are presenting one by strong lithostructural control. There is an association of areas with planning modeled are marked by strong lithostructural control. There is an association of areas with planing modeled and areas of medium dissection.

The planing areas are represented by slightly undulations hills, characterized in unit 5, where the predominant elements are of the flat type, with 28%, slope, 25%, and shoulder, with 10% of the total geomorphons elements. The dissection portions are represented in the geomorphological region of Western Edge Saw (Serra da Borda Ocidental) and principally Sincorá Saw (Serra do Sincorá) (Figure 10A), with landforms of the undulations hills associated with large hills and buttes, unit 9 landforms, where the elements are of the broad slope and spur.

In the Paraguaçu basin, the southern portion of the geomorphological region of the Central Pediplane of Diamantina Plateau (Chapada Diamantina) is represented by the landforms unit 4, which is characterized by forms of slightly undulations hills with flat top broad elements of the flat type, with 44% and slope with 23% of the total elements. The landforms are related to the presence of a Paleogenic Detritus Lateritic Coverage (Cobertura Detrítica-lateritica Paleogenica) possibly originated from the old pediplanes.

In the northern portion of the basin, on the eastern Sincorá edge saw (Figura 10A), occurs depression with important changes in the forms of relief, interpreted due to the variation of the tectonic domain. There is a sequence of lithologies formed in the Neoproterozoic sedimentary basin of the Irecê of the São Francisco Craton, formed by sequences of fine to coarse calcarenites and calcilutites developed as a consequence of extension events that occurred between 900 and 600 Ma (CONDIE, 2002). Geomorphologically it represents the Solto Soares Landing region (Patamar do Solto Soares) (Figure 10H), karstic control areas with weak dissection models and planed surfaces, in addition to dissolution processes. The flat area, as unit 1 of landforms, is represented by the flat element with more than 80% of the total area.

On the eastern Sincorá edge saw the karst areas are associated with sedimentary rocks in the Una-Utinga Basin, constituting the geomorphological region of the Utinga Landing (Patamar da Utinga), with where a are predominant of the landforms type slightly undulations hills, however, with variations that allow it to be divided into two portions. In the southern portion, the landforms develops almost entirely on limestone rocks presenting forms of slightly undulations hills associated with undulations hills marked by elongated slope and ridge elements next to the river valleys, defined by the landforms of the unit 5.

In the North portion, the association with flat areas is important, developing a relief, represented by unit 3 of landforms, where the shapes are a series of pediplanes with dissection processes on Paleogenic Detritus Lateritic Coverage (Cobertura detrítica laterítica) and associated with areas of quartz metarenite plateaus of the Mesoproterozoic. The flat element in this unit corresponds to almost half of the entire unit. This Landforms, unit 3, is also associated with the geomorphological region of Morro do Chapéu Plateau (Chapada do Morro do Chapéu) (Figure 10G).

Leaving the area of the first step of the Diamantina Plateau the Paraguaçu River penetrates its middle course, in relief carved on the pediplanation surface of the Paraguaçu Cycle, forming the Paraguaçu Surface. The medium course is characterized by areas with low rainfall and the presence of open Caatinga (semiarid biome), in shallow and stony soils. River courses are intermittent or even ephemeral; they are characterized by a fast and variable flow, closely dependent on rainfall, with floods characterized by a rapid rise in water level (IBGE, 1999). In this area there is a transition from depression to an elevated area that corresponds to the region of the Middle Paraguaçu Plateau with the springs of the Tupim, Capivari and Peixe rivers. It constitutes, tectonically, the Archean Sheets (Arqueano Lençóis) a block formed by basement rocks. The western and eastern edges of the Landing (Patamar) consist of relief of rolling hills, landforms unit 6, on a substrate of Paleoproterozoic granitoids and

Paleoarquean gneisses, forming an association of slope, ridges and valleys. There is observed through the elements of the landforms that the transition at the western edge is gradual, while at the eastern one it is abrupt.

The highest areas of the Middle Paraguaçu Landing (Patamar do Médio Paraguaçu) are formed by a heavily dissected relief with hills, buttes and large hills that occur aligned with steep slopes controlled by deep fractures and faults, represented by the landform unit 10, marked by short slopes, ridges and narrow valleys. The lithologies are represented by Archean sequences of gneisses, metagranitoids and metavolcanics, and metasedimentary rocks. In this type of landforms, the elements of the peak and pit are relatively important.

Included in this landforms unit occur a very peculiar shape, marked by the oriented ridge and wide slopes, associated with the exposure of an intrusion of metabasite Paleoproterozoic that constitutes the Orobó Saw (Serra do Orobó) (Figure 10D).

In the extreme south, truncated by the main channel of the Paraguaçu River, it develops in a landforms of slightly undulations hills, defined by landforms unit 2, which constitutes the Middle Paraguaçu Pediplane (Pediplano do Médio Paraguaçu). It transitions to the Southwest to landforms unit 10, which represents a set of large hills lined with ridges and escarpments surrounded by narrow valleys where the drainage network representing the Hills of Middle Paraguaçu (Morrarias do Médio Paraguaçu . To the Southeast, there is landforms of the rolling hills, unit 6, in the Maracás Plateau.

The Paraguaçu River channel advances to the East, crossing the relief of Unit 8 with the shape of hills and Middle Paraguaçu hills (Figure 10B), and areas of undulated hills of Middle Paraguaçu Pediplane. This landforms unit is characterized by an association of flat (23%), slope (19%), valley (15%) spur (10%) and hollow (10%) elements.

The medium course of the Paraguaçu River basin changes to a flattened surface with flat land and slightly undulations hills, where flat elements predominate, with more than 70% of the total and dispersed shoulder and footslope elements, which determine the landform unit 2 (Figure 10E). This region is composed of Precambrian basement rocks composing the tectonic environment of the orogenic belt formed by the Salvador-Curaça domain in the North, represents the Jacuopé Depression and, in the South, the Jequié domain representing the Middle Paraguaçu Pediplane. It occurs as portions within unit areas that mark landforms of the flat areas, landform unit 1, associated with the presence of Paleogenic Detritus-Lateritic Coverage, forming buttes with flat tops, and covering portions of the basement where the flat element corresponds to more than 80% of the total elements.

Other forms, which occur dispersed in this wide flat relief, are the large hills lined with longitudinal ridges and isolated massifs, landforms unit 7 (Figure 10E), identified by elements of the slope, spur and ridge type, which develop, predominantly, on granite bodies of the Proterozoic.

In the lower course, the Paraguaçu River undergoes an inflection towards the Southeast controlled by the Barreiras Formation and Recôncavo Basin, that form the springs on the left bank of the Jacuípe River, the last important tributary of Paraguaçu, where the featureds represented by landforms unit 7, which are forms large hills and buttes scattered in slightly undulating areas, which represent the region of Hills of Lower Jacuípe (Morraria do Baixo Jacuípe).

The Paraguaçu River reaches the Pedra do Cavalo dam (Figure 10C), built in the 1980s, promoted changes in the hydrological regime and affected the estuarine region (GENZ, 2006), from the lower course of the river, passing through the Iguapé Bay to the Paraguaçu River channel -BA. In the area that comprises the flooded area of the Pedra do Cavalo dam, the substrate is gneisses of the Precambrian with many areas covered by the Paleogenic Detritus lateritic Coverage forming the Country Trays (Tabuleiros Interioranos). It constitute a relief of an association of slightly undulated hills and undulated hills that representings the landforms unit 5 and the landform flat areas, determined by the unit 1, are related to the top portions of Paleogenic Detritus – Lateritic Coverage.

Downstream from the Pedra do Cavalo dam to the Bay of Iguapé, the Paraguaçu river flows over rocks of the Precambrian basement with a dissection relief of the Pre-Coastal Trays (Patamares Pré-Litorâneos) (Figure 10F) characterized by undulated hills with narrow slope elements and ridge elements, spur and associated short valleys. In the Iguapé Bay (Figure 10I), the contact of these lands with the basement occurs through a rupture of the relief. This coincides with the fault that delimits the eastern edge of the Recôncavo basin with Cretaceous age, where there is a transition from landforms undulating hills to slightly undulations hills and flat areas (unit 2) next to Todos os Santos Bay with sandy and mangroves.

5. Conclusion

This work confirms that landforms can be described and quantified into simple relief elements by parameterization of digital elevation model (DEM). In this research, the investigation of the morphometric parameters using equations applied to numeric models to characterize elemental forms associated with landforms, provide an input for pattern-based query tool capable of identifying all local landscapes similar to a given reference.

In this sense, associating the geomorphons elements and landforms with the nature of the lithologies and diverse structural was possible to describe and analyze the relief in 1 to 10 distributed from the upper course of the Paraguaçu River represented by the high plateau named Chapada Diamantina and the plane areas successively placed to downstream and characterized by slightly undulations each with specific elements.

The combination of different mapping techniques combined with increasingly modern and accessible digital mapping methodologies makes it possible to enrich the descriptions and expand the discussions on mapping in river basins, while using traditional mapping works in Brazil. The Paraguaçu River basin has a complex morphology and the combination of these different mappings and methods allowed the definition of ten landforms units.

This results expand the discussion on the use the digital relief-modeling theme to describe and assist in the construction of more detailed systematized geomorphological maps.

Contribuições dos Autores: A participação efetiva de todos autores foi essencial para o desenvolvimento de todas as etapas deste trabalho. Concepção, L.O.A, L.E.S.R e R.T.; metodologia, L.E.S.R e R.T.; software, R.T.; validação, L.E.S.R e R.T.; análise formal, L.O.A, L.E.S.R e R.T.; pesquisa, L.O.A, L.E.S.R e R.T.; recursos, L.E.S.R e R.T.; preparação de dados, L.O.A, L.E.S.R e R.T ;escrita do artigo, L.O.A, L.E.S.R e R.T.; revisão, L.O.A, L.E.S.R e R.T.; supervisão, L.E.S.R.. Todos os autores leram e concordaram com a versão publicada do manuscrito.

Financiamento: Esta pesquisa não recebeu nenhum financiamento externo, mas teve o apoio de bolsas PQ para realização do trabalho.

Agradecimentos: Os autores agradecem a Universidade Federal do Rio Grande do Sul (UFRGS) e a Universidade Federal de Santa Maria (UFSM) pela disponibilidade de estrutura e tempo para realização das pesquisas. Agradecem também aos revisores anônimos que através de comentários e sugestões contribuíram para o aperfeiçoamento e qualidade do artigo.

Conflito de Interesse: Os autores declaram não haver conflito de interesse.

Bibliographic Reference

1. ALLEN, P.A. & ALLEN, J.R.L. **Basin Analysis: Principies and Applications.** Oxford: Blackwell, 1990. 426 p.

2. ANA - AGÊNCIA NACIONAL DE ÁGUAS. **Bacias Hidrográficas Ottocodificada**. Disponível: <http://dadosabertos.ana.gov.br> Acesso em : 10 maio 2020.
3. BOLONGARO-CREVENNA, A.; TORRES-RODRÍGUEZ, V.; SORANI, V.; FRAME, D.; ORTIZ, M. A. 2005. Geomorphometric analysis for characterizing landforms in Morelos State, Mexico. **Geomorphology,** 67, 407-422. DOI:10.1016/j.geomorph.2004.11.007
4. CARVALHO, L. M. de. **Geodiversidade do estado da Bahia** / Organização Luiz Moacyr de Carvalho [e] Maria Angélica Barreto Ramos. – Salvador: CPRM, 2010.
5. CONDIE, K. C. **The supercontinent cycle: Are there two patterns of cyclicity?** Journal of African Earth Science - J AFR EARTH SCI. 35. 179-183, 2002. DOI: 10.1016/S0899-5362(02)00005-2
6. INSTITUTO BRASILEIRO DE GEOGRAFIA E ESTATÍSTICA (IBGE). Ministério da Fazenda. **Folha SD.24 Salvador: potencial dos recursos hídricos/IBGE.** Departamento de Recursos Naturais e Estudos Ambientais. Rio de Janeiro: IBGE, 1999. 236 p. - (Levantamento de recursos naturais; v.24, supl.).
7. INSTITUTO BRASILEIRO DE GEOGRAFIA E ESTATÍSTICA (IBGE). Coordenação de Recursos Naturais e Estudos Ambientais. **Mapa Temático-Relevo do Brasil**. Rio de Janeiro, 2006. Escala de 1:5.000.000: Disponível em: <http://i3geo.inde.gov.br/i3geo/interface/openlayers.htm?_dd3ac426701fb2dd690552b76bdb28e4>. Acesso em: 03 jan. 2020.
8. INSTITUTO DO MEIO AMBIENTE E RECURSOS HÍDRICOS (INEMA). **Programa Monitora: Qualidade das águas do Estado da Bahia.** RPGA do Rio Paraguaçu. Campanha 03, 2014.40p.
9. INSTITUTO DO MEIO AMBIENTE E RECURSOS HÍDRICOS (INEMA). **Inventário das Barragens do Estado da Bahia.** 2020. Disponível: <http://www.inema.ba.gov.br/gestao-2/barragensreservatorios/>. Acesso em: 10 maio 2020.
10. IWAHASHI, J.; PIKE, R. J. 2007. Automated classifications of topography from DEMs by an unsupervised nested-means algorithm and a three-part geometric signature. **Geomorphology** 86, 409-440. DOI: https://doi.org/10.1016/j.geomorph.2006.09.012
11. JASIEWICZ, J.; STEPINSKI, T. F. Geomorphons-a pattern recognition approach to classification and mapping of landforms. **Geomorphology**, v. 182, 2013. DOI:https://doi.org/10.1016/j.geomorph.2012.11.005
12. GENZ, F**. Avaliação dos efeitos da barragem pedra do cavalo sobre a circulação estuarina do Rio Paraguaçu e Baía de Iguape**.2006. Tese (Doutorado em Geologia) - Instituto de Geociências, Universidade Federal da Bahia, Salvador. 2006. 245p.
13. GERENTE, J.; VALERIANO, M. M.; MOREIRA, E. P. **Regionalização de variavéis morfométricas para o mapeamento dos domínios morfoestruturais da bacia hidrográfica do Rio Itajuí-Açu (SC).** Rev. Bras. Geomorfol. (Online), São Paulo, v.19, n.3 (Jul-Set) p.433-446, 2018. DOI: http://dx.doi.org/10.20502/rbg.v19i3.1387
14. KRETSCH, J. L. Shuttle radar topography mission overview. In: Proceedings 29th Applied Imagery Pattern Recognition Workshop*, 2000, Washington,* DC, USA. **Proceedings…** Institute of Electrical and Eletronical Engineers: IEEE Explore, 2002**.** p. 276-282. ISBN**:**0-7695-0978-9.DOI: 10.1109/AIPRW.2000.953635
15. LIAO, W.-H. **Region Description Using Extended Local Ternary Patterns**. [S.l: s.n.], 2010. p. 1003–1006. Disponível em: <http://ieeexplore.ieee.org/document/5595845/>. DOI: 10.1109/ICPR.2010.251
16. MACMILLAN, R. A.; SHARY, P. A. 2009. Landform and landform elements in geomorphometry. in: Hengl, T.; Reuter, H. I. (eds.) Geomorphometry - Concepts, Software, Applications, **Series Developments in Soil Science** 33, 227-254. DOI: https://doi.org/10.1016/S0166-2481(08)00009-3
17. MINÁR, J.; EVANS, I. S. Elementary forms for land surface segmentation: the theoretical basis of terrain analysis and geomorphological mapping. **Geomorphology** 95, 2008, 236–259. DOI: https://doi.org/10.1016/j.geomorph.2007.06.003

18. MINATEL TINÓS, T. FERREIRA; M, V.; RIEDEL, P. S.; ZAINE, J. E.. Aplicação e avaliação de metodologia de classificação automática de padrões de formas semelhantes do relevo. **Revista Brasileira de Geomorfologia**, v. 15, p. 353–370, 2014. DOI: 10.20502/rbg.v15i3.455
19. MUÑOZ, V. A. **Análise Geomorfométrica de Dados SRTM Aplicada ao Estudo das Relações Solo-Relevo**. 1. ed. Dissertação (Mestrado em Sensoriamento Remoto). São José dos Campos: 2009.
20. OJALA, T.; PIETIKÄINEN, M.; MÄENPÄÄ, T. Multiresolution gray-scale and rotation invariant texture classification with local binary patterns. **IEEE Transactions on Pattern Analysis and Machine Intelligence**, 2002. DOI: 10.1109/TPAMI.2002.1017623
21. PINEDA M. J. E.; ROBAINA L. E. S.; TRENTIN, R.; PARTIDA R. D. L. Clasificación de unidades geomorfológicas en la cuenca del Río Neverí, Venezuela. **Ra'e Ga: Temático de Geomorfologia.** Curitiba, v.41, p. 189 - 207, 2017. DOI: http://dx.doi.org/10.5380/raega.v41i0.52344
22. PONÇANO, W. L.; CARNEIRO, C. D. R.; BISTRICHI, C. A.; ALMEIDA, F. F. M.; PRANDINI, F. L. **Mapa Geomorfológico do Estado de São Paulo**. São Paulo: Instituto de Pesquisas Tecnológicas, 1981. 94p.
23. ROBAINA, L. E. D. S.; TRENTIN, R.; LAURENT, F. Compartimentação do estado do Rio Grande do Sul, Brasil, através do uso de geomorphons obtidos em classificação topográfica automatizada. **Revista Brasileira de Geomorfologia**, v. 17, n. 2, 30 jun. 2016. DOI: 10.20502/rbg.v17i2.857
24. SEIJMONSBERGEN, A. C.; HENGL, T.; ANDERS, N. S. Semi-Automated Identification and Extraction of Geomorphological Features Using Digital Elevation Data. In: SMITH, M. J.; PARON, P.; GRIFFITHS, J. (Eds). **Geomorphological Mapping: Methods and Applications, Developments in Earth Surface Processes**.1 st Edition. v. 15. Elsevier Science, 2011**.** ISBN: 9780444535368. DOI:10.1016/B978-0-444-53446-0.00010-0
25. SILVEIRA, R. M. P.; SILVEIRA, C. T. Classificação hierárquica automatizada de formas do relevo no estado do Paraná apoiada na modelagem digital do terreno. **Revista Brasileira de Geografia Física**, v. 8, n. 3, p. 1509–1523, 2015. DOI: https://doi.org/10.26848/rbgf.v8.5.p1509-1523.
26. SILVEIRA, C.T. da; SILVEIRA, R.M.P.; TRENTIN, R.; ROBAINA, L.E.S. Classificação automatizada de elementos de relevo no estado do Paraná (Brasil) por meio da aplicação da proposta dos geomorphons. **Rev. Bras. Geomorfol**. (Online), São Paulo, v.19, n.1, (Jan-Mar) p.33-57, 2018. DOI: http://dx.doi.org/10.20502/rbg.v19i1.1263.
27. SOUZA, J. D.; MELO, R.C.; KOSIN, M. (Coords.). **Mapa Geológico do Estado da Bahia -Escala 1:1.000.000**. Salvador: CPRM, 2003, versão 1.1. Programas Carta Geológica do Brasil ao Milionésimo e Levantamentos Geológicos Básicos do Brasil (PLGB). Convênio de Cooperação e Apoio Técnico-Científico CBPM-CPRM. Disponível em: http://rigeo.cprm.gov.br/xmlui/handle/doc/8665>. Acesso em: 03 jan. 2020.
28. SUPERINTENDÊNCIA DE ESTUDOS ECONÔMICOS E SOCIAIS DA BAHIA (SEI). Secretaria do Planejamento, Ciência e Tecnologia. **Tipologia Climática Köppen**. Salvador. SEI, 1998. Disponível em: https://www.sei.ba.gov.br/site/geoambientais/mapas/pdf/tipologia_climatica_segundo_koppen_2014.pdf>. Acesso em: 10 maio 2020.
29. STRAHLER, A. N. Dynamic basis of geomorphology. **Bulletin of the Geological Society of America**, 1952.
30. TRENTIN, R. & ROBAINA, L. E. S. Metodologia para Mapeamento Geoambiental no Oeste do Rio Grande do Sul. In: Simpósio Brasileiro de Geografia Física Aplicada, 11, 2005, São Paulo. **Anais...** São Paulo: USP. 2005.
31. TRENTIN, R.; ROBAINA, L. E. D. S.; BARATTO, D. D. S. **Análise de elementos do Relevo através do Topographic Position Index (TPI) da Bacia Hidrográfica do Arroio Puitã – Oeste do Rio Grande do Sul/Brasil**. Geography Department University of Sao Paulo, 2016. DOI https://doi.org/10.11606/rdg.v31i0.100267

32. VIDAL-TORRADO, P.; LEPSCH, I. F.; CASTRO, S. S. **Conceitos e aplicações das relações pedologia-geomorfologia em regiões tropicais úmidas**. In: Tópicos em Ciência do Solo [S.l: s.n.], v. 4. p. 145-192, 2005.
33. WILSON, J. P. Digital terrain modelling. **Geomorphology**, 137, p.107–121, 2012. DOI:10.1016/j.geomorph.2011.03.012
34. WILSON, J. P.; GALLANT, J. C. (eds.). **Terrain analysis: principles and applications**. New York: John Wiley & Sons, p.1-27, 2000.