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STUDY OF THE LANDFORMS OF THE IBICUÍ RIVER BASIN WITH USE OF TOPOGRAPHIC POSITION INDEX

ESTUDO DOS ELEMENTOS DE RELEVO DA BACIA HIDROGRÁFICA DO RIO IBICUÍ COM O USO DO ÍNDICE DE POSIÇÃO TOPOGRÁFICA

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Abstract:

The Topographic Position Index (TPI) is an algorithm which calculates the difference of the elevation between a central pixel (and the mean of the elevation of its surroundings ($\overline{Z}$) surroundings defined by of a radius determined by the user. The study was developed in the Ibicuí Basin, located in the west of Rio Grande do Sul, with a surface area of 46,602.58 km², with a perimeter of 1,268.76 km and an 8th order hierarchy. The TPI analysis associated with inclination determined 08 landforms elements in the BHRI: flat area elements, top elements identified as flat and wavy, springs, slopes and the footslopes and channel elements that can be closed or opened.

Resumo:

O Índice de Posição Topográfica (IPT) é um algoritmo que calcula a diferença de elevação entre um pixel central (e a média dos ambientes de elevação do ambiente ($\overline{Z}$) definidos por um raio determinado pelo usuário. O estudo foi desenvolvido na Bacia hidrográfica do rio Ibicuí, localizado no oeste do Rio Grande do Sul, com uma área de 46.602,58 km², com um perímetro de 1.268,76 km e uma hierarquia da 8ª ordem. A análise IPT associada à inclinação determinou 08 elementos de relevo no BHRI: elementos de área plana, elementos de topo identificados como planos e ondulados, nascentes, encostas, base da encosta e elementos de canal que podem ser fechados ou abertos.

Introduction

Studying of the landforms is of fundamental importance for environmental studies since it conditions the flow of materials and energy in the landscape. The intensities of the surface dynamics processes are sensitive to the topographic position, however, there is great difficulty in measuring the attributes to specify their description, due to their spatial variability (LONGLEY *et al.*, 2015). The possibility of obtaining topographic indexes that adequately represent these complex variables is one of the current challenges of environmental modeling.

Geographic information systems (GIS) have emerged as an effective way of integrating and articulating different data sources through spatial reference (MAGUIRE; DANGERMOND, 1991). The analytical capacity of GIS can be used effectively in the field of landscape analysis Joliveau (2003) and with emphasis on landscape components (CHELTAT, 2005).

Using this tool the current methods of classification allowed the subdivision into landforms elements, which are a set of plots of a relatively homogeneous relief type. Several authors have described the relief from the topographic variables obtained from the digital terrain models (DTM) (MACMILLAN; SHARY, 2009); (MUÑOZ, 2009); (VASCONCELOS *et al.*, 2012); (JASIEWICZ, STEPINSKI, 2013) (SILVEIRA; SILVEIRA, 2015, 2014, 2016); (TRENTIN, ROBINA, BARATTO, 2016); (ROBAINA *et al.*, 2017).

The authors Jasiewicz; Stepinski (2013) have established automated geomorphological parameterization in so-called geomorphons. Applying this methodology Robaina *et al.* (2017) compartmentalized the state of Rio Grande do Sul into seven landforms.

In this context Weiss (2001) presents and describes the concept of the Topographic Position Index (TPI) and how it can be calculated. Using the TPI at different scales and associated with declivity can be classified the different elements of the slope. The topographic position index is a tool that enables the determination of landscape features taking into consideration the topographical attributes of the study area thus defined the units have a close relationship with flow conditions and fluid dynamic surface.

The classification using TPI is the difference between elevation value on pixel and the average elevation of the neighboring pixels. Positive values mean that the analyzed pixel has values greater than the surrounding values, while negative indicates that it is smaller.

The degree to which the pixel is greater or less, added declivity that it has can be used to classify the position on the slope. When the value is significantly higher it may indicate area near the top or ridge; when significantly lower indicates valley; values close to zero can mean flat area or in the half-slope, so the declivity can be used to distinguish.

Using these methodology Trentin; Robaina; Baratto (2016) determined the different elements of the slopes in the Puitã basin, West of Rio Grande do Sul, using the analysis of the Topographic Position Index. The TPI classes determined were: valleys; flat areas; gentle slopes; wavy slopes; steep slopes and top of slopes. Silveira; Silveira (2017) determined the relief forms of Paraná by applying the Topographic Position Index (TPI), followed by the evaluation of its distribution in the morpho sculpture subunits of the Paraná Geomorphological Map.

The present work integrates the TPI data in different scales and the pixel declivity to determine the relief elements in the Ibicuí river basin, RS.

Methodology

The Ibicuí River basin, geographically it is located (Figure 1) between the latitude 29º01 ‘and 31º20’ South and between longitudes 56º47 ‘and 53º29’ West. The basin area is 46,602.58 km², with a perimeter of 1268.76 km and has an 8 th order hierarchy, as classified by STRAHLER (1952).

According to Carraro *et al.*, (1974), geomorphologically the basin occurs in the volcanic and sediments of the Peripheral Depression and Plateau, in addition to a small portion in the South-Riograndense Shield. Recently Robaina *et al.*, (2010) established a geomorphological division of the Ibicuí Basin, composed of the Peripheral Depression, Serra Geral Plateau and the SW portion of the South-Riograndense Shield.

The digital base for the analysis and discrimination of the elevation was the Digital Elevation Model derived from radar data SRTM (Shuttle Radar Topography Mission) available from the US Geological Survey site with spatial resolution of 3 Arc second (approximately 90 meters) (KRETSCH, 2000).

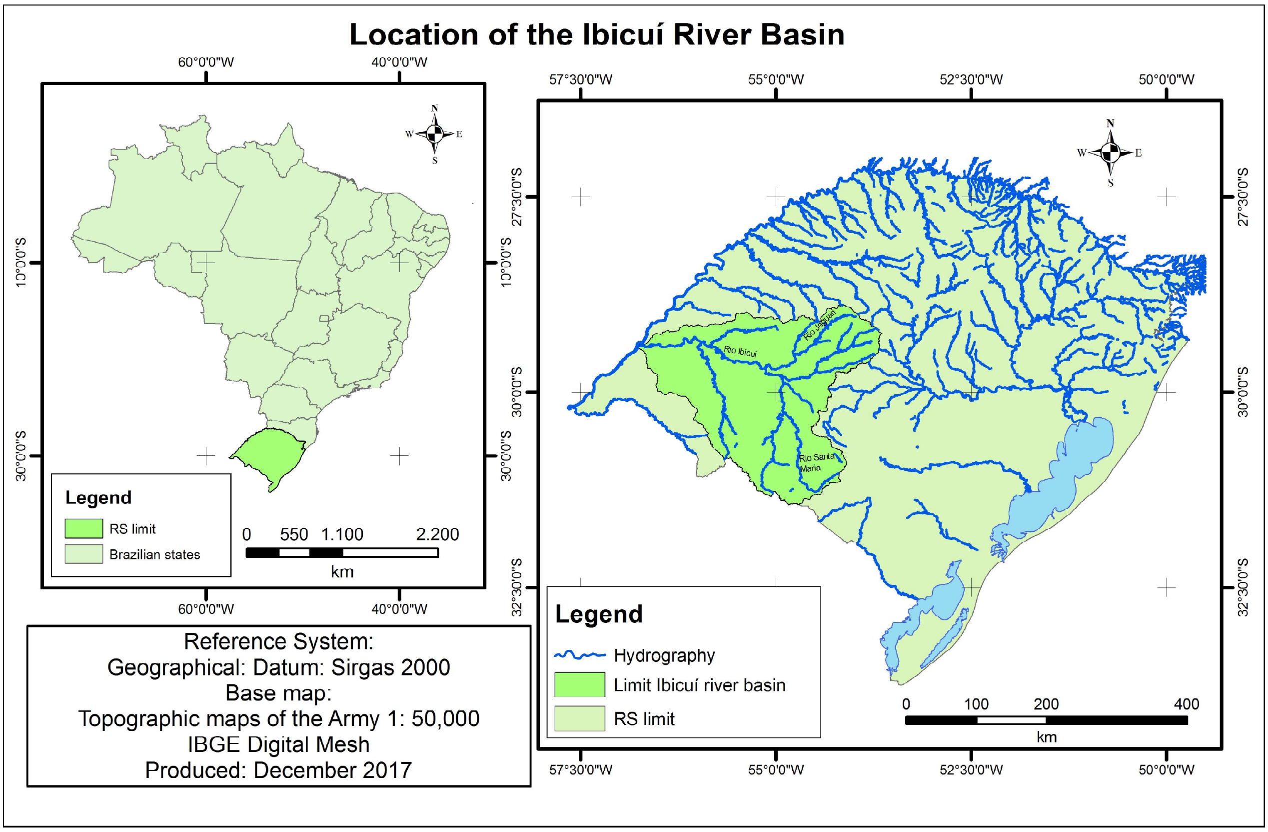

Figure 1 - Location map of the Ibicuí River Basin (BHRI)

The version 4.1 of the SRTM data Kretsch (2000), which has anomalous corrections and spurious pixels, in addition to the application of water masks. The reference datum for the processing was Wgs84, in order to avoid data transformations. In the data processing, a rectangle defined by the coordinates of the upper left corner and the coordinates of the lower right corner, plus a buffer of 10 km was used in order to avoid any edge effects in the results of the processing. After the application of the methodological procedures, the data was cut for elaboration of the final map with the use of the spatial limit of the hydrographic basin.

The organization and processing of the database was done with the software ArcGIS 10.2 GIS (ESRI, 2011), using the basic database extensions and spatial analyst and 3D analyst extensions for data processing and raster crossing (REUTER; NELSON, 2009).

The Topographic Position Index (TPI) is an algorithm created by Weiss (2001), which calculates the difference of the elevation between a central pixel (Z_0) and the mean of the elevation of its surroundings ($\overline{Z}$) surroundings defined by of a radius determined by the user, equation 1.

$$IPT = Z_0 - \overline{Z}$$

The value of TPI expresses the intensity of the contrast, allowing to highlight ridges or peaks that are substantially higher than their adjacent cells. Significantly negative TPI values suggest that the cell is near the bottom of a valley. The TPI is directly related to the scale of analysis Jenness; Brost; Beier (2013), as can be seen in Figure 1. The TPI is calculated to the same point on the landscape using three different scales. In each case, the point is located at the top of a small hill, situated inside a larger valley. In case A, the scale is large enough that the point is more or less the same height as the region of analysis in this way the TPI value would be approximately 0. In case B, the region of analysis is large enough to cover the entire small hill, and the point is therefore much larger than its neighbors, thus presenting a corresponding high value for the TPI. In case C, the scale includes the hill and both sides of the valley, and therefore the point is lower than its neighbors, presenting a negative value for the TPI (JENNESS; BROST; BEIER, 2013; TRENTIN; ROBAINA; BARATTO, 2016).

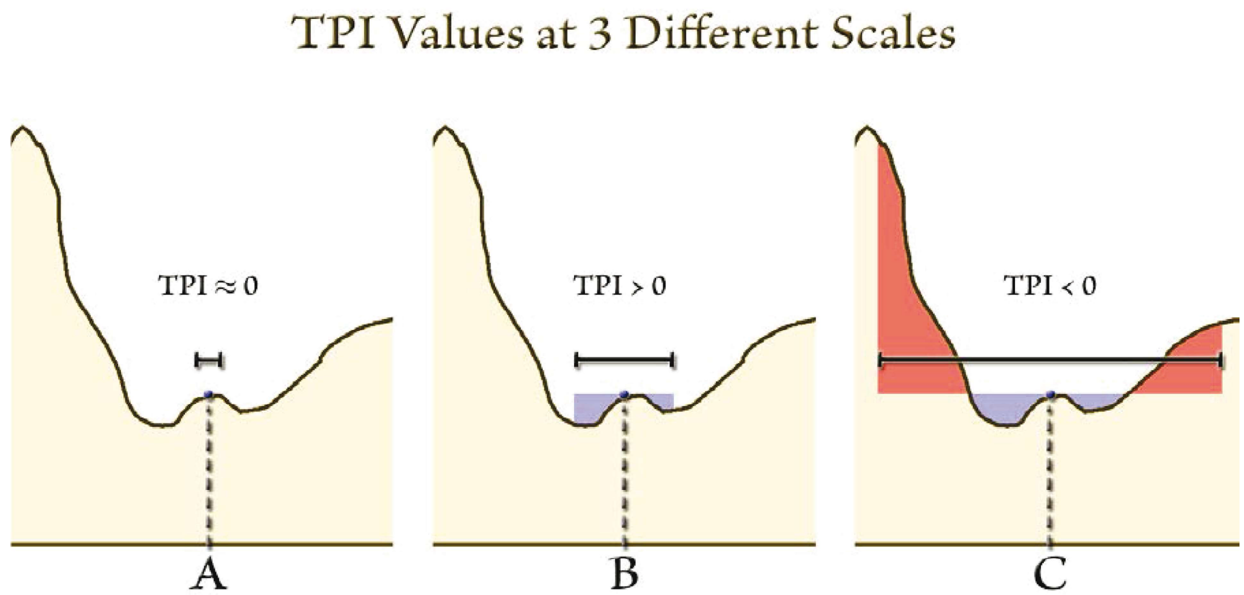

Figure 2 - TPI calculated with different radii of analysis of the environment

The surroundings analysis in ArcGIS is performed by a mobile window that can be circular, ring, rectangular, among others, through the tool "focal statistics", defining a user-defined statistical operation. In the present work we used the circular moving window with statistical operation of the mean.

For the definition of the units of the hydrographic basin of the Ibicuí river, the raster crossing was composed of three sets of information: TPI regional, TPI local and inclination. The TPI Regional data were defined using the analysis radius of surrounding to calculate the average altitude of approximately 1450 meters (16 pixels); the TPI Local data were defined using the analysis radius of surrounding to calculate the average altitude of approximately 270 meters (3 pixels); for the inclination data the percentage was used.

For the data set, information plans, (Regional TPI and Local TPI), we established three classes, using as class limits the standard deviation of the data, in this way we defined the classes: low elevations in relation standard deviation to the surrounding (TPI <-1); classes of altitudes similar in relation standard deviation to the surrounding (TPI > -1 and <1); altitude classes higher than the standard deviation to the surrounding (TPI > 1). For the inclination information plane, two classes of analysis were used, with the class limit being the interval of 5% (IPT,1981), since this limit is associated with the beginning of erosive processes.

After the crossing of information plans, they were organized and defined eight units: Wavy Top; Slopes; Plan; Plane Top; Springs; Closed Channel; Open Channel and Footslope. Table 1 shows the parameters used to define the units.

Table 1: Parameters used for the definition of relief units in the Ibicuí river basin.

	Regional TPI	Local TPI	Inclination
1 Wavy Top	< -1 SD	< -1 SD	> 5%
2 Slope	> -1 SD < 1 SD	< -1 SD	> 5%
	> -1 SD < 1 SD	> -1 SD < 1 SD	> 5%
	< -1 SD	> -1 SD < 1 SD	> 5%
	< -1 SD	> 1 SD	> 5%
3 Plane	> -1 SD < 1 SD	> -1 SD < 1 SD	< 5%
4 Plane Top	< -1 SD	< -1 SD	< 5%
	> -1 SD < 1 SD	< -1 SD	< 5%
	< -1 SD	> -1 SD < 1 SD	< 5%
	< -1 SD	> 1 SD	< 5%
	> 1 SD	< -1 SD	< 5%
5 Springs	> -1 SD < 1 SD	>1 SD	< 5%
	> 1 SD	>1 SD	< 5%
6 Closed Channel	> -1 SD < 1 SD	>1 SD	> 5%
	> 1 SD	>1 SD	> 5%
7 Open Channel	> 1 SD	> -1 SD < 1 SD	< 5%
8 FootSlope	> 1 SD	> -1 SD < 1 SD	> 5%
	> 1 SD	< -1 SD	> 5%

Results

The Ibicuí River basin covers important rivers in the Western region of Rio Grande do Sul, partially or totally draining the area of 30 municipalities and is the largest tributary of the Uruguay River within Brazilian territory.

In the portions above 300m, there are drainage headwaters half-moon shaped forming small depressions in the ground. The passage from the highest altitude areas of the Plateau to the low altitude of the Depression is due to a relief with the presence of steep valleys in the area of Plateau Border.

The forms of hills are predominant and are characterized by slope between 5-15%, on average 8%, and amplitudes between 40m and 60m.

Landforms Elements

The TPI analysis associated with declivity determined 08 landforms elements in the BHRI: flat area elements, top portions identified as flat and wavy, drainage headwaters, slopes and footslopes and channel closed or opened. The Figure 3 shows the spatial distribution of the units and table 2 shows the area and percentage of these units in the BHRI.

Table 2: Area and percentage of relief element units in the BHRI.

	Area km²	Percentage
Wavy Top	1.982,06	4,20
Slope	8.105,57	17,19
Plane	26.786,93	56,82
Plane Top	2.792,55	5,92
Springs	1.291,39	2,74
Closed Channel	3.323,17	7,05
Open Channel	2.007,10	4,26
Footslope	853,00	1,81

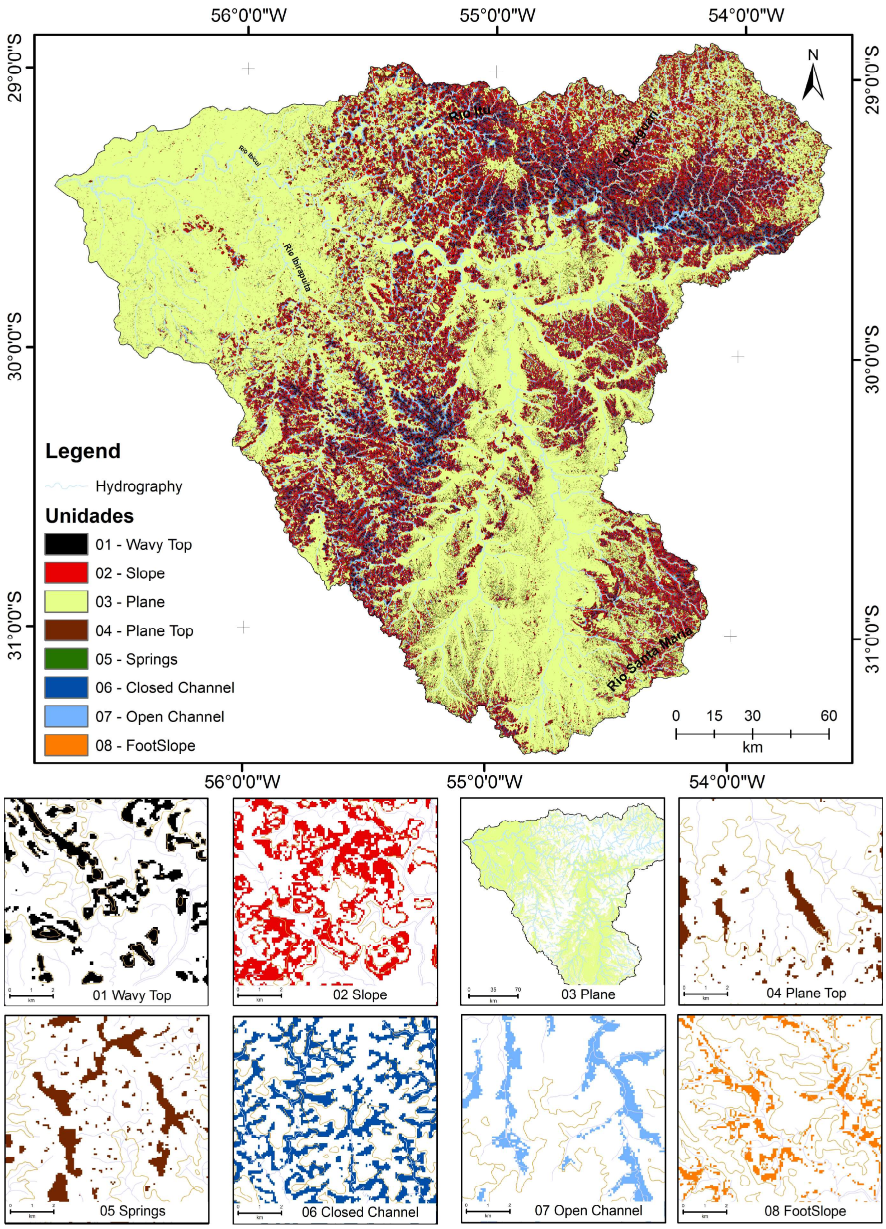

Figure 3 - Spatial distribution of BHRI Relief Element Units

The landforms flat elements predominate, comprising 26,787km², which corresponds to 57% of the basin. Occur forming a large area in the basin of the Santa Maria river. The Santa Maria river flows from South to North and when meeting the Ibicuí-mirim river constitutes the Ibicuí river. The landforms of large interfluves and area with slopes around 2%, gives situations of hydromorphism and high content of clays 2:1. Figure 4 shows the flat areas in sequences of lamitic rocks. This unit is also important on a substrate of volcanic rocks interspersed with sandstones that form the Western portion of the Ibicuí river toward the mouth at the Uruguay river. The characteristics are altitudes lower than 100m, forms with large interflúvios, slopes between 2% and 5%, can generate shallow soils until well developed, but generally with 2: 1 clays due to the low lateral transport capacity of the products of the reactions.

Figure 4 - Flat areas on marine sequences.

In the non-flat areas, formed by landforms of hills and buttes, the units of the slope elements are important, with 8,105.57 km², corresponding to 17.195% of the basin (Figure 5).

The footslopes elements occur at 853.00 km², which corresponds to 1.81% of the basin. They are represented in the transition from the strongly undulating landforms identified by well-defined slopes and the valleys elements, often constituting colluvial deposits (Figure 5).

Figure 5 – Slope and footslope elements on hills and buttes at the Caverá Serra (A) and Border Plateau (B).

The flat top elements occupy 2,792.55km², corresponding to 5.92% of the basin. While the elements of wavy tops with 1,982.06 km² correspond to 4.2% of the basin. The first occur in the gently undulating landforms of hills and buttes supported by sandstones. The second is associated with the landforms of hills and buttes supported by volcanic rocks (Figure 6).

Figure 6 – Hills and Buttes of the wavy tops elements (A) and plane tops elements (B).

The springs elements occur throughout the basin, occupying 1,291.39km², 2.74% of the basin. It constitutes small areas in the top of semicircular form, with convergence of flow. Figure 7 shows situations of drainage headwaters.

The elements defined as channels, mark the incisions in the landforms generated by the water action. The closed channels occur in 7.05% of the basin, with an area of 3,323.17 km², while the open channels correspond to 4.26% of the basin, in an area of 2,007.10 km². The closed channels occur associated with the landforms at the Border Plateau, at the *Serra do Caverá* and in portions of the Shield (Figure 8A). The open channels form the incisions at the top of the Plateau and the medium and low rivers course in contact with the flat areas (Figure 8B).

Figure 7 – Springs elements in headwaters at Plateau.

Figure 8 – Channels closed on landforms of the strong wavy hills (A) and Channels open on landforms of the hills (B).

Final Considerations

A method is to define threshold TPI values in terms of standard deviations from the elevation, which therefore take into account the variability of elevation values within that neighborhood. This means that grid cells with identical TPI value may be classified differently in different areas, depending on the variability in their respective neighborhoods.

Using the TPI at different scales and associated inclination can be classified the different elements of landforms.

In the context of the automated classification of landforms the TPI application was simplified and representative for different units of landforms observed in the basin.

The application of TPI has the potential as an auxiliary tool to geomorphological cartography studies.

References

CARRARO, C. . *et al.* **Mapa Geológico do Estado do Rio Grande do Sul (escala 1:1.000.000)** Porto AlegreUFRGS - Instituto de Geociências, , 1974.

CHÉTELAT, J. **Eléments méthodologiques de diagnostic paysager utilisant les systèmes d'information géographique**. [s.l.] Ecole polytechnique Fédérale de Lausanne, 2005.

ESRI. **ArcGIS Desktop: Release 10Redlands CA**, 2011.

JASIEWICZ, J.; STEPINSKI, T. F. Geomorphons — a pattern recognition approach to classification and mapping of landforms. **Geomorphology**, v. 182, p. 147–156, 2013.

JENNESS, J.; BROST, B.; BEIER, P. Land Facet Corridor Designer: Extension for ArcGIS. **Jenness Enterprises**, 2013.

JOLIVEAU, T. Analyse des paysages dans un contexte d'aménagement. L'intérêt des outils géomatiques. **Géoévénement**, p. 4–6, 2003.

IPT. Instituto de Pesquisas Tecnológicas. **Mapeamento Geomorfológico do**

Estado de São Paulo. São Paulo. Escala 1:500.000, v. 2, 1981. 130 p.

KRETSCH, J. L. **Shuttle radar topography mission overview**. Proceedings - Applied Imagery Pattern Recognition Workshop. **Anais**...Institute of Electrical and Electronics Engineers Inc., 2000

LONGLEY, P. *et al.* **Geographic Information Science and Systems**. 4Th. ed. Chichester: Wiley, 2015.

MACMILLAN, R. A.; SHARY, P. A. Chapter 9 Landforms and Landform Elements in Geomorphometry. **Developments in Soil Science**, v. 33, p. 227–254, 2009.

MAGUIRE, D. J.; DANGERMOND, J. The functionality of GIS. In: P. LONGLEY (Ed.). . **Geographic Information Systems and Science.** 1st. ed. Chichester: Wiley, 1991. p. 319–335.

MOORE, I. D.; BURCH, G. J. Modelling erosion and deposition: topographic effects. **Transactions of the ASAE**, 1986.

MOORE, I. D.; BURCH, G. J.; MACKENZIE, D. H. Topographic Effects on the Distribution of Surface Soil Water and the Location of Ephemeral Gullies. **Transactions of the ASAE**, 1988.

MOORE, I. D.; GRAYSON, R. B.; LADSON, A R. Digital Terrain Modeling : A Review of Hydrological Geomorphological and Biological Applications. **Hydrological Processes**, 1991.

MUÑOZ, V. A. **Análise Geomorfométrica de Dados SRTM Aplicada ao Estudo das Relações Solo-Relevo**. 1. ed. São José dos Campos: Dissertação (Mestrado em Sensoriamento Remoto), 2009.

REUTER, H. I.; NELSON, A. Chapter 11 Geomorphometry in ESRI Packages. **Developments in Soil Science**, v. 33, p. 269–291, 2009.

ROBAINA, L. E. DE S. *et al.* COMPARTIMENTAÇÃO GEOMORFOLÓGICA DA BACIA HIDROGRÁFICA DO IBICUÍ, RIO GRANDE DO SUL, BRASIL: PROPOSTA DE CLASSIFICAÇÃO. **Revista Brasileira de Geomorfologia**, v. 11, n. 2, p. 11–23, 2010.

ROBAINA, L. E. DE S. *et al.* APPLICATION OF THE CONCEPT OF GEOMORPHONS TO THE LANDFORM CLASSIFICATION IN TOCANTINS STATE, BRAZIL. **Raega - O Espaço Geográfico em Análise**, v. 41, n. 0, p. 37, 28 ago. 2017.

SILVEIRA, C. T.; SILVEIRA, R. M. P. ÍNDICE DE POSIÇÃO TOPOGRÁFICA (IPT) PARA CLASSIFICAÇÃO GEOMORFOMÉTRICA DAS FORMAS DE RELEVO NO ESTADO DO PARANÁ - BRASIL. **Raega - O Espaço Geográfico em Análise**, v. 41, n. 0, p. 98, 28 ago. 2017.

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.

SILVEIRA, R. M. P.; SILVEIRA, C. T. DA. MORPHOLOGICAL CLASSIFICATION OF TERRAIN OF URUGUAY BASED ON DIGITAL ELEVATION MODELS AND GEOMORPHOMETRIC TECHNIQUES. **Geografía y Sistemas de Información Geográfica (GEOSIG).**, v. 6, n. Sección I, p. 19–36, 2014.

SILVEIRA, R. M. P.; SILVEIRA, C. T. DA. ANÁLISE DIGITAL DO RELEVO APLICADA À CARTOGRAFIA GEOMORFOLÓGICA DA PORÇÃO CENTRAL DA SERRA DO MAR PARANAENSE. **Revista Brasileira de Geomorfologia**, v. 17, n. 4, 15 dez. 2016.

STRAHLER, A. N. HYPSOMETRIC (AREA-ALTITUDE) ANALYSIS OF EROSIONAL TOPOGRAPHY. **GSA Bulletin**, v. 63, n. 11, p. 1117–1142, 1 nov. 1952.

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.

VASCONCELOS, V. *et al.* Sistema De Classificação Geomorfométrica Baseado Em Uma Arquitetura Sequencial Em Duas Etapas: Árvore De Decisão E Classificador Espectral, No Parque Nacional Serra Da Canastra. **Revista Brasileira de Geomorfologia**, 2012.

WEISS, A. Topographic position and landforms analysis. **Poster presentation, ESRI User Conference, San Diego, CA**, 2001.