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A methodological proposal to map the dissection of the relief and apply it in the Serra da Canastra-MG National Park

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A methodological proposal to map the dissection of the relief and apply it in the Serra da Canastra-MG National Park[1]

Abstract

Our study proposes a map of the relief dissection using the bivariate geovisualization technique. This map allows us to verify the influence of each variable; notching of the valley and interfluvial dimension, separately or combined. The Serra da Canastra National Park, southwest of the state of Minas Gerais, was chosen to apply the method due to its geomorphologic characteristics and altimetry amplitude. The results presented by bivariate map, showed equivalence with the other proposals existing in the Brazilian literature, with good precision and spatial correlation, mainly where the dissection is "very strong". The methodology has the advantage of universality, since its application does not depend on the database used, without requiring interference by decision makers, based on the digital elevation model (DEM) of any geographic region.

Keywords: Relief dissection. Bivariate Geoview. Serra da Canastra National Park.

Uma proposta metodológica para mapear a dissecação do relevo e aplicá-la no Parque Nacional da Serra da Canastra-MG

Resumo

Este trabalho propõe um mapa da dissecação do relevo por meio da técnica de geovisualização bivariada. Esse mapa permite verificar a influência de cada variável, entalhamento do vale e dimensão interfluvial, de forma separada ou combinada. O Parque Nacional da Serra da Canastra, no sudoeste de Minas Gerais, foi escolhido para aplicação do método devido a suas características geomorfológicas e a sua amplitude altimétrica. O resultado do mapa bivariado

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apresentado mostrou equivalência com outras propostas aplicadas existentes na literatura brasileira, com boa precisão e correlação espacial, principalmente onde a dissecação é "muito forte". A vantagem dessa metodologia é a universalidade, pois sua aplicação independe da base de dados utilizada e prescinde da interferência do tomador de decisões, a partir do modelo digital de elevação (MDE) de qualquer região geográfica.

Palavras-chave: Dissecação do relevo. Geovisualização bivariada. Parque Nacional Serra da Canastra.

Una propuesta metodológica para mapear la disección del relieve y aplicarla en el Parque Nacional Serra da Canastra-MG

Resumen

Se propone un mapa de disección de relieve por medio de la técnica de geovisualización bivariada. El mapa posibilita verificar la influencia de las variables; inclinación del valle y dimensión interfluvial, de forma separada o combinada. El Parque Nacional Serra da Canastra, suroeste de Minas Gerais, fue elegido para la aplicación del método debido a sus características geomorfológicas y amplitud altimétrica. El resultado del mapa bivariado presentado mostró equivalencia con las otras propuestas aplicadas existentes en la literatura brasileña, con buena precisión y correlación espacial, especialmente donde la disección es "muy fuerte". La metodología tiene como ventaja la universalidad, ya que su aplicación no depende de la base de datos utilizada, sin necesidad de interferencia del usuario, a partir del modelo digital de elevación (MDE) de cualquier región geográfica.

Palabras clave: Disección en relieve. Geovisualización bivariada. Parque Nacional Serra da Canastra.

Introduction

The relief dissection index is a fundamental morphometric parameter to understand the genesis of landscapes and help in environmental planning and management (Ross, 1994). It can be used for several purposes: to understand the organization and evolution of landscapes, to assess environmental fragility and to detect risk areas, among others.

Currently, there is an increasing need for the public administration to have updated documents that guide the planning of occupation centered on the principle of sustainable and/or balanced development to indicate different levels of restriction on use and occupation. Thus, our study presents a proposal for mapping the dissection index applied to the Serra da Canastra National Park (SCNP), a parameter that helps to understand environmental dynamics and preservation practices at different scales.

Queiroz Neto (1978) analyzes the results obtained in studies and scientific research that address different aspects of the environment and its use: rational land use, potential in natural resources, consequences of uses in water and air, search for alternative solutions for uses of renewable and non-renewable natural resources. The author notes "the absence of research and studies, and even guidance, on the obtention of a global assessment of the elements of the environment, including the two dynamics, both natural and degradation, pollutants and control systems" (QUEIROZ NETO, 1978, p. 5). In this sense, the dissection index is easy to obtain and greatly contributes to the overall assessment of environmental elements.

The use of recent technological advances – especially the development of geotechnologies – is changing the state of the art in concepts and in the development of geographic research methodologies. Geographic Information System (GIS), geoprocessing and remote sensing products stand out, which allow integrating techniques to theoretical concepts, besides enabling the storage of various types of geographic data. They are important mechanisms of analysis, study and planning of space. By orbital satellite images, it is possible to analyze structure and dynamics of the landscape at different spatial and time scales, varying according to the sensor configuration (Albuquerque et al., 2014).

With eminent ecotourism potential, the SCNP is in the southwestern part of the state of Minas Gerais, bordering São Paulo, being a conservation unit of integral protection. Despite the park's importance, there are still no in-depth studies on the dynamics and degradation of the environment, and the mapping of morphometric indices can support studies in this direction (e.g., dissection). Aspects such as the region's geomorphological characteristics, such as large altimetric amplitude and heterogenic relief forms, explain the choice for the experimental area of our study.

The methodological proposals for mapping the dissection of the relief available in the Brazilian literature, theoretically supported by the dissection matrix proposed by Ross (1994), are dependent on fundamentally pre-established thresholds. The classification is made according to the proposition of these thresholds, which depend fundamentally on the existing database, especially on the topographic characteristics of the terrain. Often, due to the physical/geographical characteristics of the study area, these methodologies may be inapplicable or unfeasible due to the values of pre-established thresholds for their application.

The main objective of our study is to present a new proposal for mapping relief dissection based on an existing bivariate geovisualization technique by Stevens, 2015, but never applied for this purpose. The final product allows us to verify the influence of each variable, carving of the valley and interfluvial dimension, separately or combined.

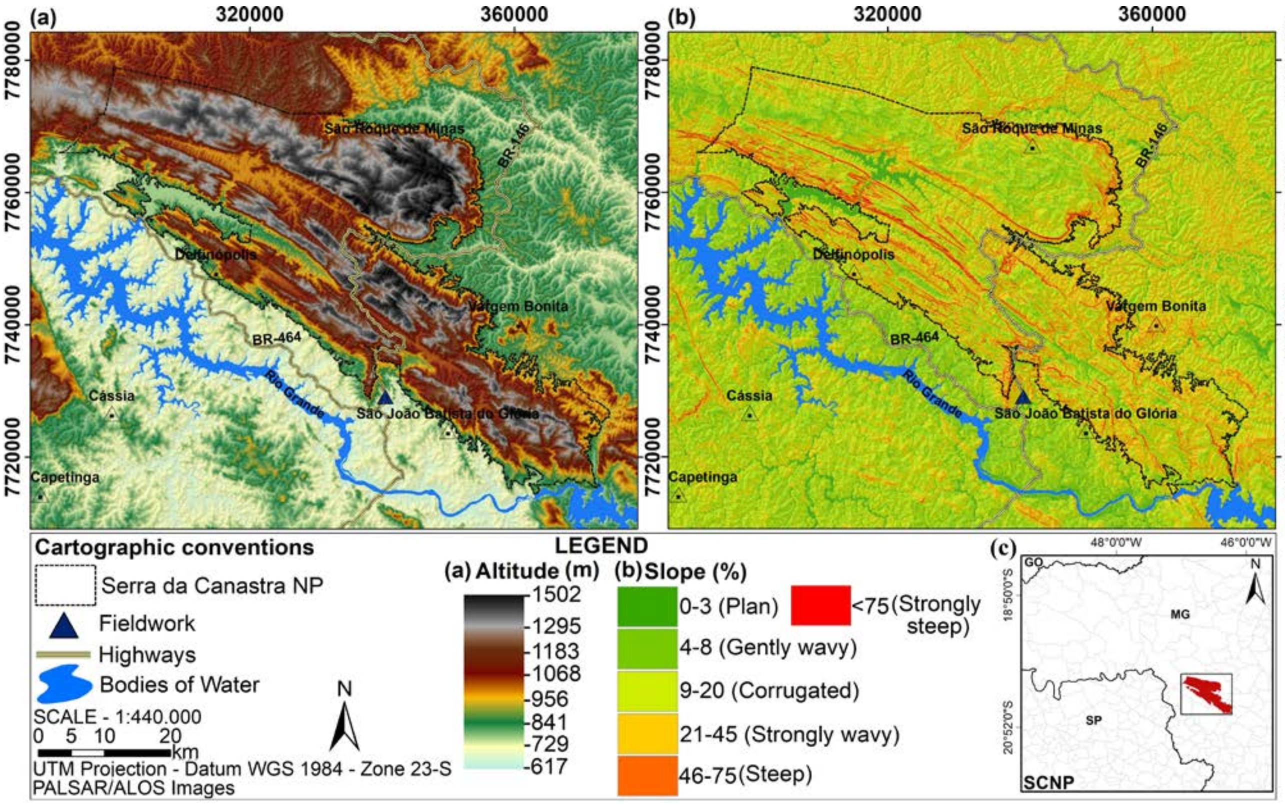
To evaluate the results obtained by the methodology adopted, the proposals of Ross (1994) and Guimarães et al. (2017) were applied in the same area and a fieldwork conducted at a specific point in the study area.

Materials and methods

Study area

The Serra da Canastra National Park (SCNP) is located in the southwest of Minas Gerais, with approximately 200,000 hectares. In the Park, there is the watershed of the basins of the São Francisco and Paraná rivers, in this case, contributing with the Rio Grande to the south and with the Paranaíba to the north. It covers four municipalities of Minas Gerais: São João Batista do Glória, Delfinópolis, São Roque de Minas and Vargem Bonita (Figure 1).

Figure 1 – Location of the study area: (a) hypsometric map, b) slope map, c) geographical situation



source: Prepared by the authors, 2020.

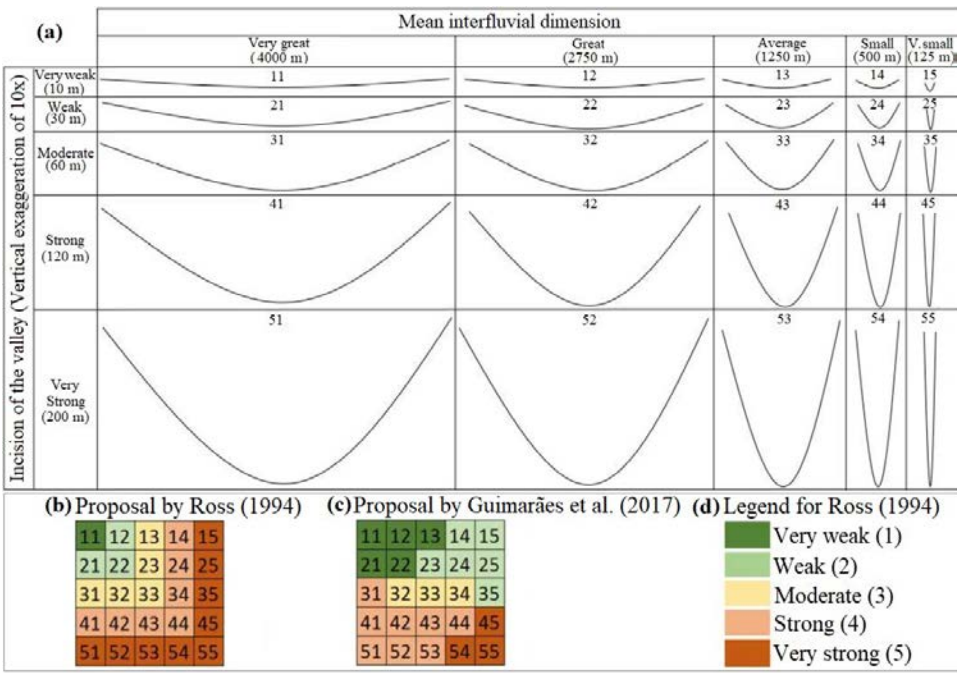
The SCNP area and its surroundings are in the Cerrado phytogeographic domain. The area belongs to grassy-woody savannah, presenting practically all phytophysiognomies that encompass forest, savanna and rural formations (IBGE, 1991, 1993). Regarding geology and geomorphology, the region of Serra da Canastra is in the transition range between the domain of the chapadões, covered by cerrados and penetrated by forest-galleries to the north, and the domain of seas and forested hills to the south, comprising a region of flat-structure massifs of complex structure and compartmentalized sedimentary plateaus (Ab'Saber, 1971). The predominant relief domains are wavy hills and plateaus, with slopes ranging from 3% to 20%, including the river plain and heavily rugged hills and hills. The river plain, often in slope less than 3% on flat terrain and slightly inclined towards the main channel, comprises the floodplain and terraces of the Rio Grande, to the south, characterizing wetland (Brasil, 1983).

The regional climate is characterized by seasonality, with rains in summer and dry winter. The average temperature of the coldest month is less than 18 °C and the hottest month does not exceed 22 °C. The area has an annual rainfall between 1,000 and 1,500 mm. The quarter from December to February, besides being the wettest, is the one with the largest water surplus and the most active surface runoff (Souza, 1993).

Theoretical-methodological rationale

Our study is based on the theoretical and methodological principles of integrated analysis of the environment, supported by the theoretical conception of the relief dissection matrix proposed by Ross (1994) (Figure 2-a). This matrix integrates the variables related to the degree of carving of the valley (on the Y axis) and mean interfluvial dimension (on the X axis), and the relief dissection is directly proportional to the first variable and inversely proportional to the second. For the automated calculation of the variables carving of the valley and interfluvial dimension, the methodology of Guimarães et al. was used (2017). Figure 2 shows valley profiles that represent each dissection value of the matrix proposed by Ross (1994) (Figure 2-a) and both the proposal for reclassification of the matrix (Figure 2-b) and the proposal by Guimarães et al. (2017) (Figure 2-c), in addition to the stratification of the legend (Figure 2-d).

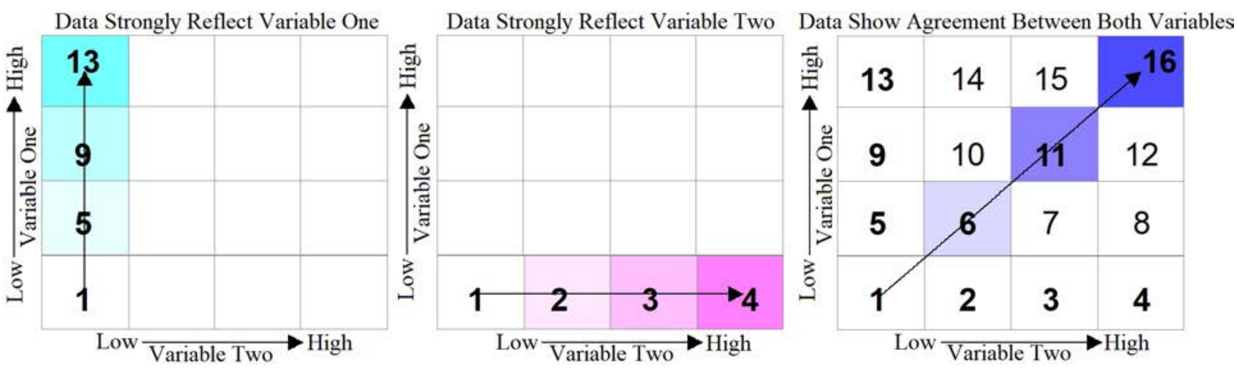
Figure 2 – (a) Profile of the valleys representing each dissection class of the Ross matrix (1994), (b) proposed classification of Ross (1994), (c) proposed by Guimarães et al. (2017), (d) legend Ross (1994)



source: Adapted from Guimarães et al. (2017).

Based on this matrix, our study tests a proposal based on the technique of bivariate geovisualization, which results is a map of the relief dissection. This product allows us to check each variable, carving of the valley and interfluvial dimension, separately and/or in a combined way. According to Stevens (2015), bivariate maps shows more than simply two variables; they show where the two variables tend to agree or at odds. If the two variables are not expected to be related, a bivariate coroplethic variable is not the right choice (Stevens, 2015). Showing interrelation of two variables is also the reason why the number of classes on a bivariate map is greater than the combined sum of classes of each variable alone. If the individual variables have n classes, the bivariate map has n^2 classes (Stevens, 2015). Based on Ross' matrix (1994) (Figure 2-a), an experiment with the representation of the carving of the valley in the Y-axis of the bivariate legend and the representation of the interfluvial dimension on the X-axis was conducted. Therefore, the two variables are expected to be interrelated, resulting in the relief dissection index. Figure 3 illustrates how the bivariate subtitle operates.

Figure 3 – Bivariate legend



Source: Adapted from Stevens (2015).

On the Y-axis, the data strongly reflect the degree of the incision of the valleys (1, 5, 9 and 13), whereas on the X-axis, they reflect the mean interfluvial dimension (1, 2, 3 and 4). Diagonally, the data express the agreement between the two variables, resulting in relief dissection (1, 6, 11 and 16). The numbers in the lower triangular submatrix (7, 8 and 12) represent the interfluvial dimension, whereas the numbers of the upper triangular submatrix (10, 14 and 15) represent the incision. The number 1 in the legend is neutral for both variables.

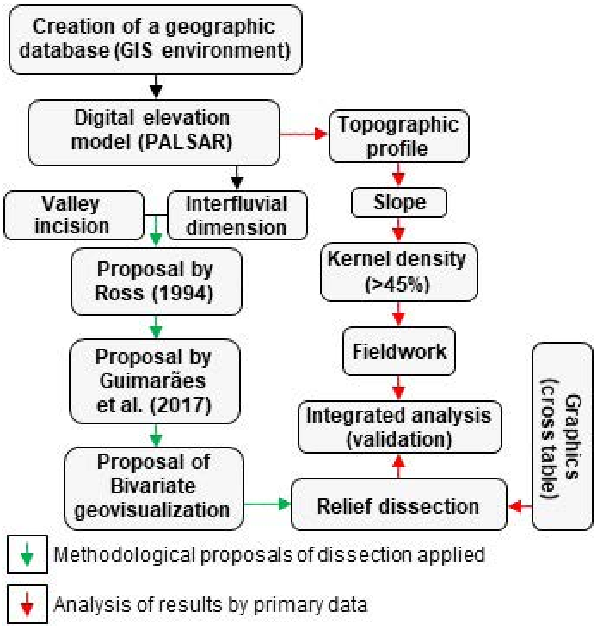
Technical procedures

The technical procedures were developed according to the steps showed in the flowchart in Figure 4.

The initial stage of the study consisted of the creation of a database containing images of the Palsar sensor (phased array type l-band synthetic aperture radar) onboard of the Alos satellite (advanced land observing satellite) from SAR (synthetic aperture radar) images acquired in FBS (fine beam) mode, HH polarization, upstream orbit with a spatial resolution of 12.5 m (L-band), obtained from the Alaska Satellite Facility (ASF) database. The collection resulted in the scenes: AP_27102_FBS_F6780_RT1; AP_27102_FBS_F6770_RT1; AP_27102_FBS_F6760_RT1;

AP_26854_FBS_F6780_RT1; AP_26854_FBS_F6770_RT1; AP_26854_FBS_F6760_RT1. Secondary data from cartographic bases in shapefile format related to roads, water mass and other cartographic elements were also used, including the municipalities that cover the study area, added to secondary data for validation of the results.

Figure 4 – Methodological flowchart



Source: Prepared by the authors, 2020.

The information and data set were organized in a geographic database for processing, conversion and analysis of results, and then implemented in a geographic information system using weighted field algebra methods. The publication scale of the mappings is 1:440,000.

Palsar Image Treatment

A mosaic was initially built with the scenes of the Palsar sensor. Then, a safety margin (buffer) was established to fit the boundary of the study area, since some of the algorithms used during processing require the values of adjacent pixels to be processed; areas located on the safety margins that are closer to the edges of the image are more subjected to errors and noise (Guimarães et al., 2017). The FillSinks algorithm was then applied to fill the spurious depressions, assigning new values to the pixels with anomalies based on information from the nearest neighbors (Wang; Liu, 2006).

Mapping of valley incision variables and mean interfluvial dimension

The mapping of the degree of the incision of the valleys and the mean interfluvial dimension followed the methodological procedures described in the study by Guimarães et al. (2017). Therefore, the author specifically points out that, in the calculation of the mean interfluvial dimension, it is necessary to determine the threshold that defines the minimum drainage area considered basin for the delimitation of drainage basins (Medeiros; Ferreira, Ferreira, Ferreira, 2009), and this threshold is given by the number of pixels. The choice of this threshold is the only step that depends on the decision of the researcher to execute the methodology. The choice of the ideal value depends on the pixel size of the DEM used and the characteristics of the relief of the study area (Guimarães et al., 2017). Unlike the study by Guimarães et al. (2017), which used Images of the DEM from images of the SRTM radar (shuttle radar topography mission), with spatial resolution of 30 m, in this study, Palsar images with spatial resolution of 12.5 m were used. Thus, after calculations and tests, a threshold of 1,724 (count/pixel) was used using the conditional/con function in the ArcGIS software (Esri, 2016). Finally, the variables were obtained, in raster format: incision of the valleys and mean interfluvial dimension.

Application of proposals for relief dissection of ross (1994), Guimarães et al. (2017) and bivariate geovisualization

After obtaining the two variables, the rasters of the degree of incision of the valleys and interfluvial dimension were reclassified according to the matrix proposed by Ross (1994) (Figure 2-a). Thus, according to the matrix, the raster of incision of the valleys was reclassified as follows: 0 to 20 m (10); 20 to 40 m (20); 40 to 80 m (30); 80 to 160 m (40); greater than 160 m (50). Subsequently, the raster of the mean interfluvial dimension was classified as follows: 0 to 250 m (5); 250 to 750 m (4); 750 to 1,750 m (3). There were no values higher than 1,750 m (2) and 3,750 m (1). Then, the classes were reclassified to assume the values in parentheses: Y-axis for incision, X-axis for interfluvial dimension.

To obtain the relief dissection index, the sum of the rasters obtained by the Plus function was made using the ArcGIS raster calculator (Esri, 2016), according to which each pixel will have a dissection value. Subsequently, two dissection maps were generated: one by grouping the classes according to Ross' proposal (1994) (Figure 2-b), the other by the proposal of Guimarães et al. (2017) (Figure 2-c)

In the application of the proposal of bivariate geovisualization for the elaboration of the relief dissection map, the variables referring to the raster of incision of the valleys and mean interfluvial dimension were classified into four classes each. However, the thresholds of the reclassified maps were not the same as those proposed in the Ross' matrix (1994) (Figure 2-a); the intervals were defined by the algorithm of natural breaks (Jenks). Thus, the proposed thresholds were: for the Y-axis (incision of the valleys); 1-43 m (1); 44-112 m (5); 113-226 m (9); 227-628 m (13); and for the X axis (mean interfluvial dimension); 1,080-1,919 m (4); 783-1,079 m (3); 530-782 m (2); 1-529 m (1). Then, the classes were reclassified in order to assume the values in parentheses: Y-axis incision, X-axis interfluvial dimension, as in the bivariate legend (Stevens, 2015) (Figura 3). The combination of the maps by the bivariate geovisualization technique resulted in the map of the relief dissection.

Validation of results

To validate the results, cross table graphs were elaborated from the stratified classes of the Kernel density map. This was performed with declivities greater than 45%. The Kernel map was reclassified into five classes and stratified into very low, low, moderate, strong and very strong density. Based on the map, graphs were elaborated using the crosstabulation technique with kernel stratifications and the results obtained by the methodologies and proposal of our study.

The maps obtained by the proposed stratifications of Ross (1994) and Guimarães et al. (2017), were reclassified into three classes. This criterion was adopted because the grouping of the map with the reclassification values proposed by Ross (1994) provides three stratifications, so the same criterion was used for the map of Guimarães et al. (2017), selecting the three top laminates. Following the same purpose and pattern, for the elaboration of the crosstab graph, with the stratified classes of the Kernel density map and the bivariate dissection map, the dissection classes (6, 11 and 16) were selected, excluding number 1, because it is unusual for both variables in the bivariate legend.

For the analysis of the results, a topographic profile was traced in a registered observation point adjacent to BR-146, by a fieldwork (January 1, 2019), near the municipality of São João Batista do Glória-MG. The coordinates of the observation point are: 340.617m E / 7,728,971m N, at an altitude of 748 m with approximately 3,200 km in length.

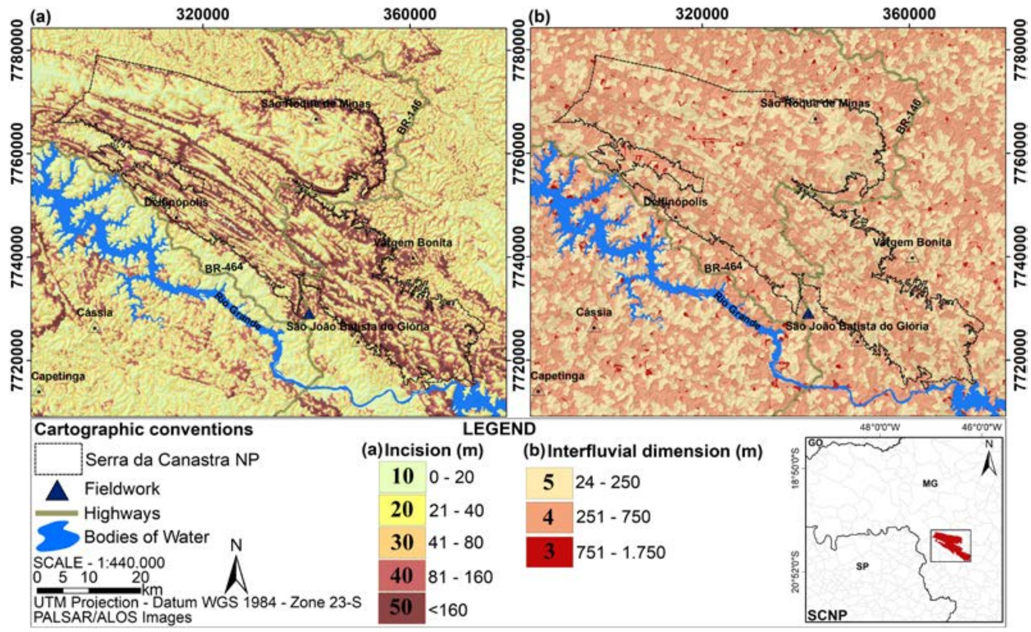
Results and discussion

Application of proposals for relief dissection of Ross (1994) and Guimarães et al. (2017)

Figure 5 shows the distribution of the classes of the variables in the studied area and Graph 1 shows the percentage of each unit of the maps.

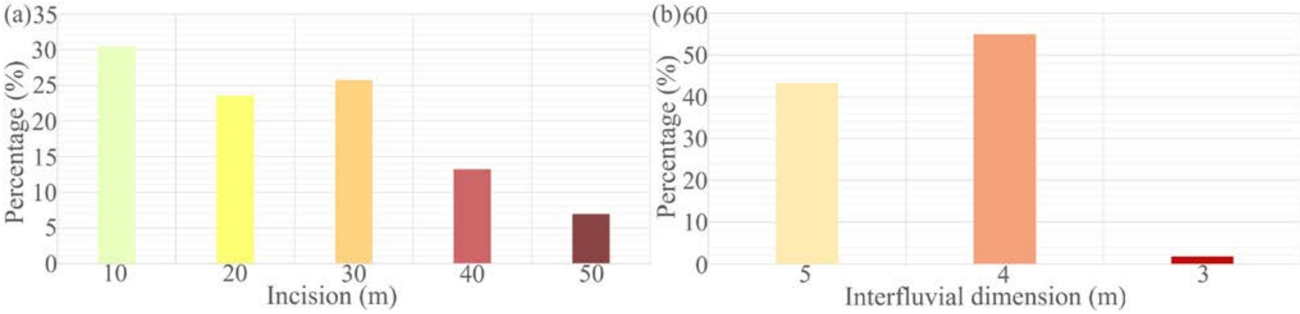
No values corresponding to the combinations were obtained in the study area: 11, 12, 21, 22, 31, 32, 41, 42, 51, and 52. The lowest values indicate areas with lower relief dissection, whereas the highest indicate stronger dissection (Guimarães et al. 2017).

Figure 5 - (a) Valley incision map, (b) Map of the average interfluvial dimension



Source: Prepared by the authors, 2020.

Graph 1 – Distribution of variables: (a) incision, (b) interfluvial dimension (Ross, 1994)

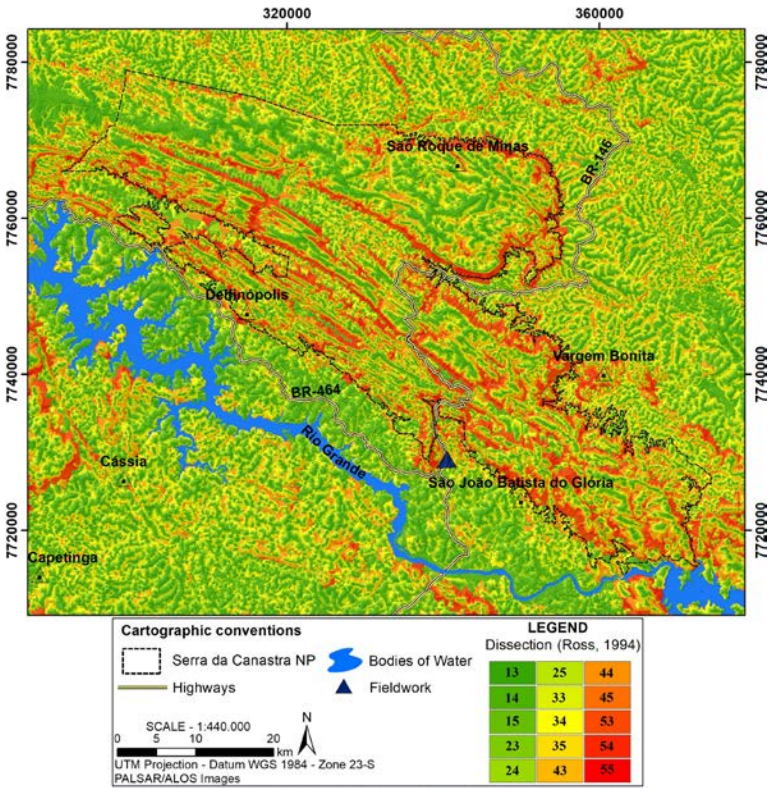


Source: Prepared by the authors, 2020.

Figure 6 shows the distribution of dissection classes in the studied area, following the Ross' matrix proposal (1994) (Figure 2-a) and Graph 2 shows the percentage of each unit of dissection of the map.

The maps presented different subtitles according to each proposal because they did not present the same classification thresholds. In Ross' proposal (1994) (Figure 2-b), only combination 11 corresponds to a "very weak" dissection class (there was no such class in the study area); on the other hand, in the proposal of Guimarães et al. (2017) (Figure 2-c), the "very weak" class considers the ranges of 11, 12, 13, 21 and 22. Consequently, maps present different stratifications in their legends (Ross, 1994) (Figure 2-d). In Ross' proposal (1994) (Figure 2-a), there were no classes "very weak" and "weak" and, thus, the map presented only the classes "moderate", "strong" and "very strong" of dissection, unlike the proposal of Guimarães et al. (2017) (Figure 2-c), which presented all classes of the stratified legend (Figure 2-d).

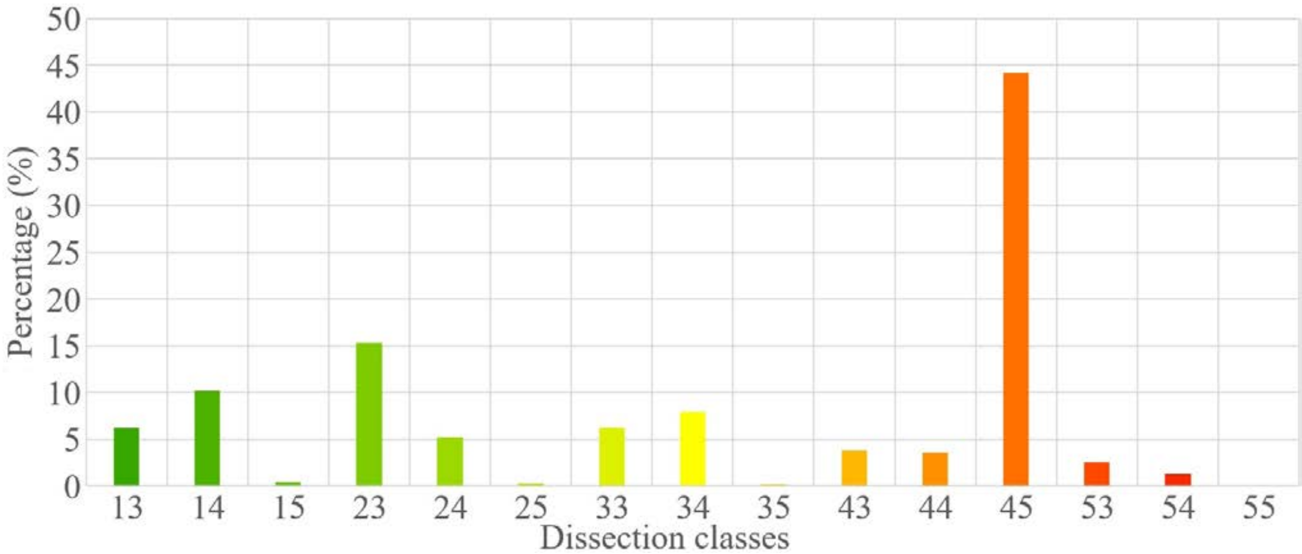
Figure 6 – Map with matrix grouping by Ross (1994) (Figure 2-a)



Source: Prepared by the authors, 2020.

MANTOVANI, J. R.; BUENO, G. T.

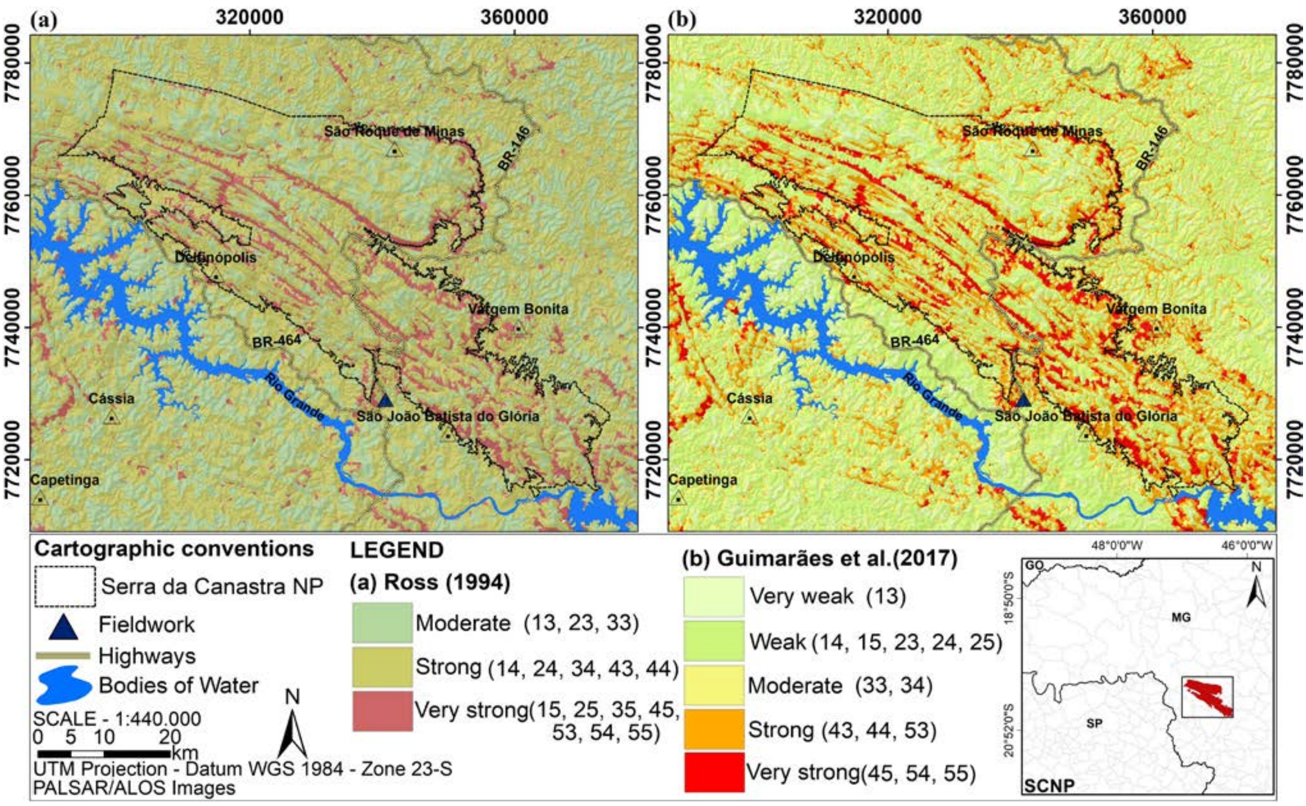
Graph 2 – Distribution of relief dissection map classes



source: Prepared by the authors, 2020.

Figure 7 shows the distribution of dissection units in the studied area obtained by the proposals of Ross (1994) (Figure 7-a) and Guimarães et al. (2017) (Figure 7-b) and Graph 3 shows the percentage of classes of dissection maps.

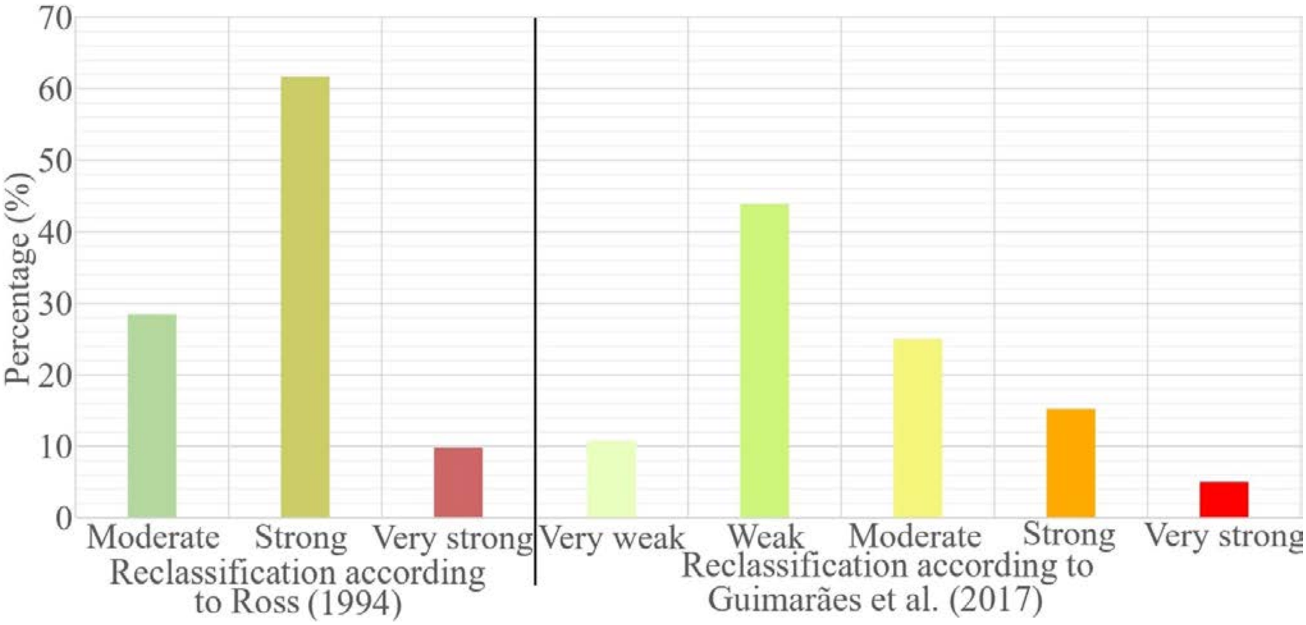
Figure 7 – Relief dissection maps: (a) Map stratified according to Ross (1994) (Figure 2-b), (b) Map stratified according to Guimarães et al. (2017) (Figure 2-c)



Source: Prepared by the authors, 2020.

MANTOVANI, J. R.; BUENO, G. T.

Graph 3 – Distribution of relief dissection map classes



source: Prepared by the authors, 2020.

The "Strong" class of Ross' map (1994) (Figure 7-a) presented the highest percentage of dissection, with approximately 62% of the total area, located between 9 and 45% of slope. It occupies wavy and strongly wavy areas distributed at different altitudes throughout the study area. The second class, the "Moderate", occupies 28% of the total dissectised area, located between 0 and 8% of slope. It occupies wavy and strongly wavy areas, distributed at different altitudes throughout the study area. Finally, the class of smallest spatial representation in the studied area belongs to the class "Very strong", with approximately 10% of the area. It is located in the slopes greater than 45% of declivity, especially steep and rugged areas of the SCNP, besides appearing in scattered points and at different altitudes.

Regarding the map according to the proposal of Guimarães et al. (2017) (Figure 7-b), the "Weak" class presented the highest spatial scope in the study area, with approximately 44% of occupation, located between 4 and 8% of slope. It is formed by slightly wavy relief areas, distributed at low altitudes along the study area. Then, we find the class "Moderate", with approximately 25% of the total area, located between 8 and 20% of slope, under wavy reliefs, distributed at altimeter levels slightly higher than the previous class. The "Strong" class occupies approximately 15% of the total area, formed by strongly wavy relief, located between 20 and 45% of slope. It is distributed at higher altimetric levels than the previous class. Then the class "Very weak", occupying approximately 11% of the total area, formed in flat reliefs. It is distributed throughout the study area at low altimetric levels, formed mainly by valley bottoms and flood plains. Finally, the "Very strong" class, with approximately 5% of the total area, formed by high slopes, with above 45% of declivity. It occupies steep areas mainly located in the park and its edges, besides appearing in scattered points at higher altitude of the study area.

Graph 3 shows that the two proposals present similar results for the "Very strong" class, although they are different. Visually, they present an equivalent spatial behavior of relief dissection distribution, mapped both in steep and in rugged areas. These areas are situated on the limits of the park, in the main watersheds.

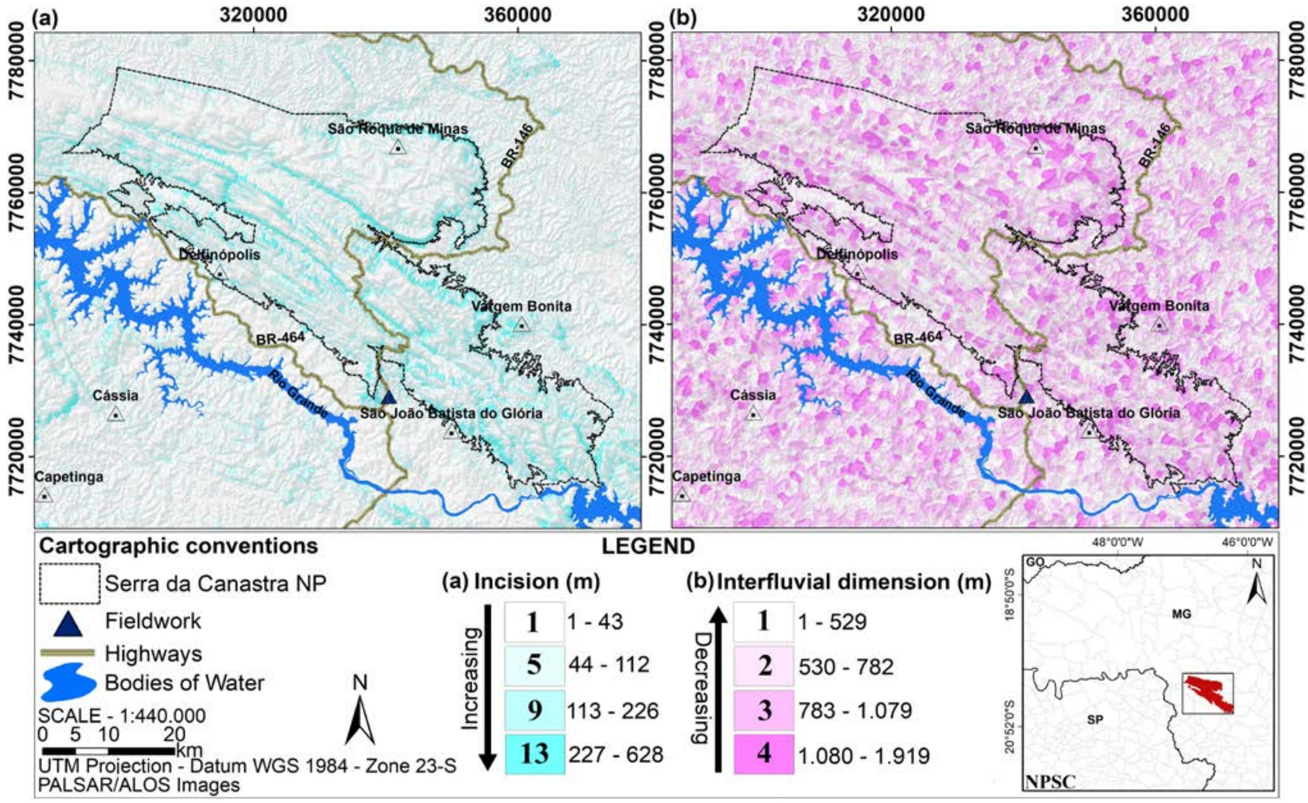
Thus, from Ross' conceptual point of view (1994), this region of the state of Minas Gerais is more susceptible to erosive processes. However, such an affirmation would require more information and parameters for analisis on a more detailed scale. In the concept by Guimarães et al. (2017), on the other hand, the cartographic representation emphasizes more accurately the properties of the land; compared to slope (Figure 1-b), the features are slightly exposed on this scale of analysis.

Bivariate geovisualization to map relief dissection

Figure 8 shows the distribution of the variables reclassified according to the proposal of bivariate geovisualization, namely incision of the valleys (Figure8-a) and interfluvial dimension (Figure 8-b) and Graph 4 shows the percentage of classes in the two maps obtained.

Values 1, 5, 9 and 13 are increasing for incision, whereas values 4, 3, 2 and 1 are decreasing for the interfluvial dimension.

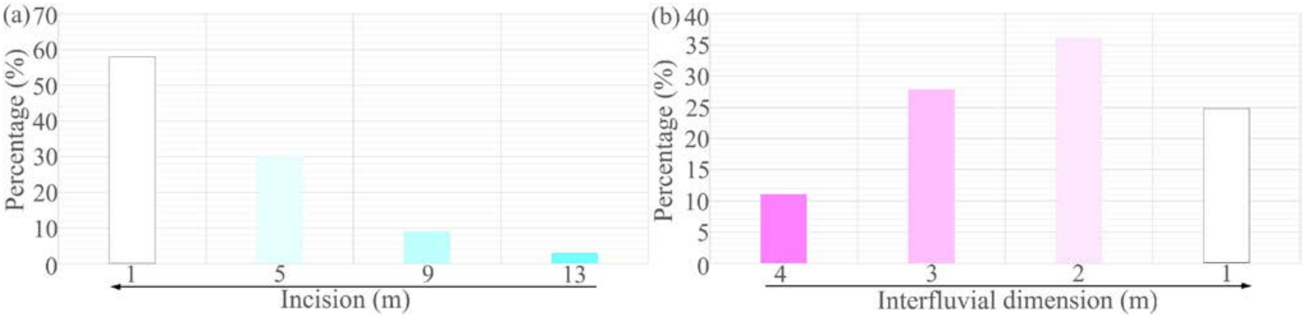
Figure 8 – Variables with the proposal of bivariate geovisualization: (a) map of incision, (b) map of average interfluvial dimension



Source: Prepared by the authors, 2020.

MANTOVANI, J. R.; BUENO, G. T.

Graph 4 – Distribution of bivariate variables: (a) incision, (b) interfluvial dimension



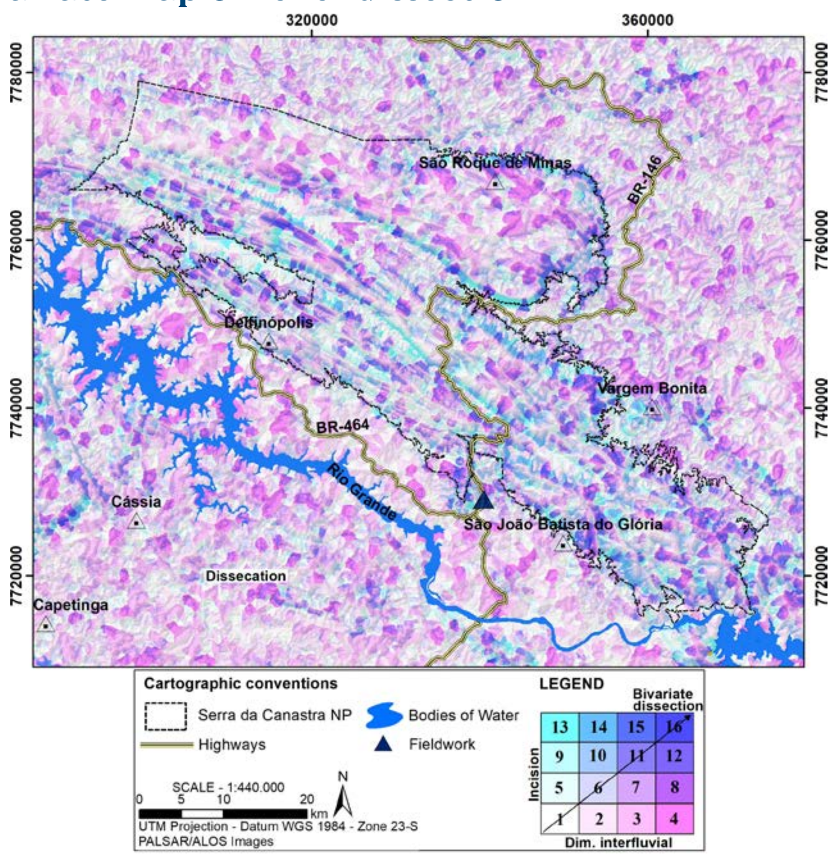
Source: Prepared by the authors, 2020.

Figure 9 shows the distribution of dissection units in the studied area, obtained by the proposal of bivariate geovizualization, and Graph 5 shows the percentage of each dissection unit in the coverage area.

In general, the results also show that dissection is higher in areas where deep, cumply, crayonvalleys, V-shaped, with small interfluvial dimension (X-axis) predominate. These areas are characterized by high incision (Y-axis), being associated with high slope sites. On the other hand, the dissection is lower in flat areas, with a larger interfluvial dimension.

The bivariate legend presents a spatial distribution of dissected areas similar to those presented by the previous proposals, especially in the areas of "very strong" dissection, which refer to number 16 in the map legend.

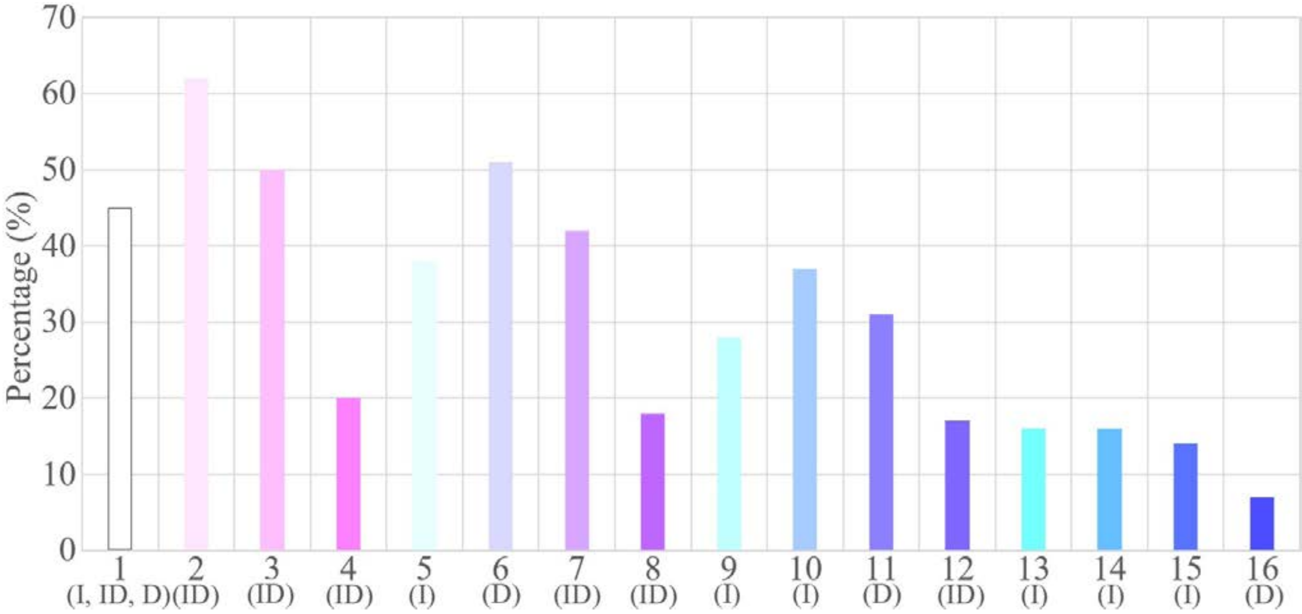
Figure 9 – Bivariate map of relief dissection



source: Prepared by the authors, 2020.

Graph 5, although the classes present spatial representations different from the results obtained by the other two proposals, shows an equivalent spatial behavior of distribution of relief dissection, mapped in steep and rugged areas. These areas are situated on the limits of the park, in the main watersheds. In some regions at the edge (cliffs) of the SCNP, some areas that appear on the other maps (Figures 7-a; 7-b) as dissected, in the bivariate proposal are classified as strong incision.

Graph 5 – Distribution of classes of the bivariate dissection map: incision (I), interfluvial dimension (ID) and dissection (D)



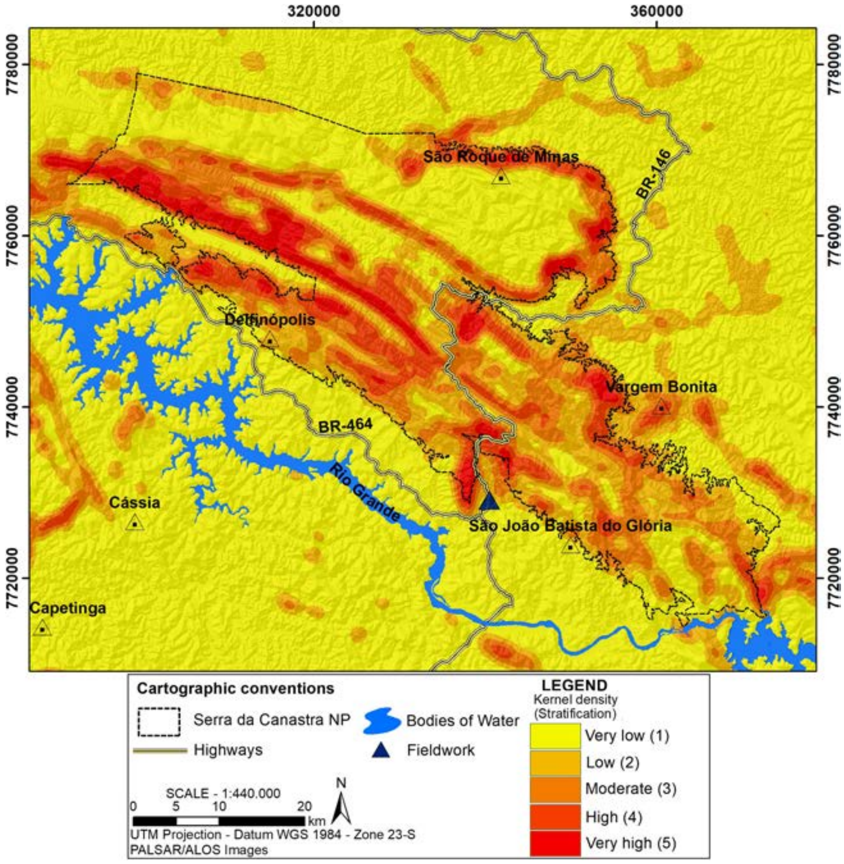
Source: Prepared by the authors, 2020.

According to Graph 5, the variable of the interfluvial dimension occupies the largest area of the dissection map (2, 3, 4, 7, 8 and 12); followed by incision (5, 9, 10, 13, 14 and 15), and by relief dissection (6, 11 and 16).

Figure 10 shows the distribution of kernel density map units and, in Graph 6, the percentage of each dissection map considering kernel map classes. In the Kernel density map, considering the slope pixels greater than 45% (Figure 10) it is possible to verify strongly steep and rugged areas, distributed mainly along the edges that skirt the park and in some isolated locations, in large watersheds.

This aspect proves that the steepest and rugged sites are situated along the edges of the Park. If we compare the maps of the dissection, visually and spatially, they present an equivalent and standardized distribution of dissection, especially in areas with the strongest dissection index.

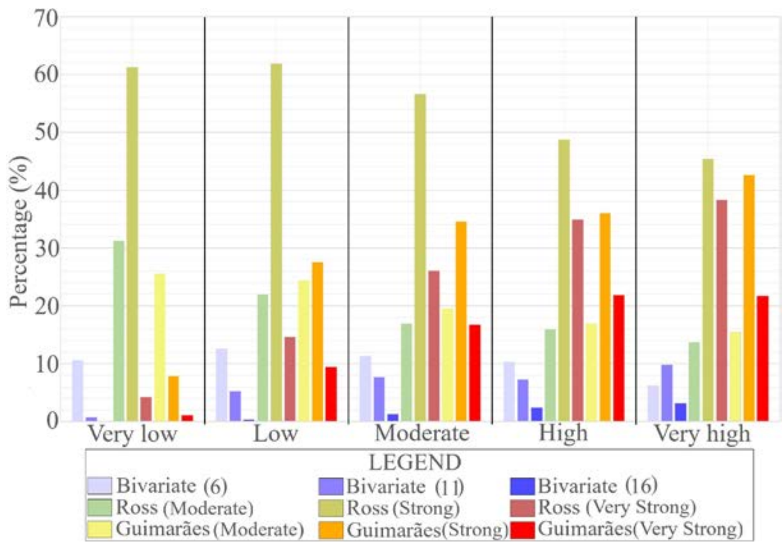
Figure 10 – Kernel Density Map



Source: Prepared by the authors, 2020.

The analysis of Graph 6 allows us to conclude that the three proposals of the dissection area, Ross (1994), Guimarães et al. (2017) and bivariate, present equivalent results for the class "Very strong".

Graph 6 - Distribution of bivariate dissections, Ross (1994) and Guimarães et al. (2017) on kernel surfaces (very low, low, moderate, high, and very high)

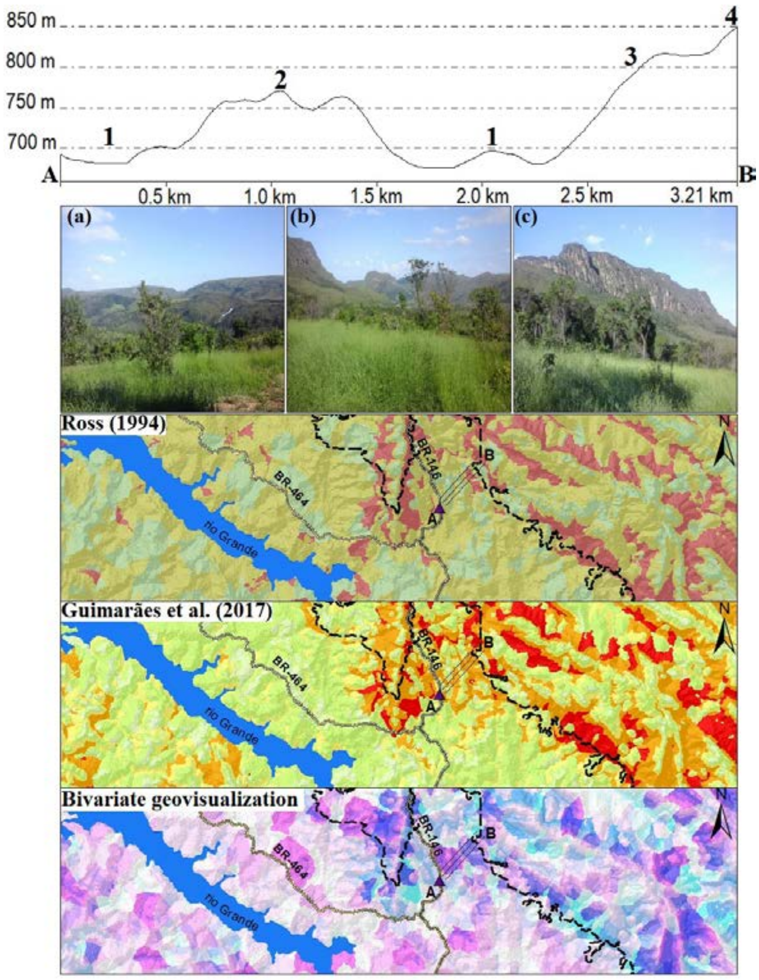


Source: Prepared by the authors, 2020.

Figure 11 shows the topographic profile (A-B) in the area where the fieldwork was conducted and the photographs were obtained (Figures 11-a at 11-c). Four compartments were identified: in compartment 1, located around 700 m above sea level, it can be seen in the corresponding photographs (a, b) that the relief consists of wider valleys and less accentuated slope. In the map obtained by bivariate geovisualization, the interfluvial dimension is the most influential factor. In Ross' proposal (1994), this compartment appears as an area of moderate dissection and in the proposal by Guimarães et al. (2017), it is located in a transition area, with very weak to moderate dissection. In compartment 2, located at about 750 m altitude (photo b), the valleys present more incisions, with the presence of steeper areas, as indicated in the map obtained by the bivariate geovisualization. In the other proposals, the representativeness of the classes of moderate and strong dissection increases. In compartment 3, located around 800 m altitude, the relief is a little more dissected (photographs a and c) and with greater influence of the incision, with the presence of cliffs at foothills. This is indicated in the three proposals by the prevalence of strongly to very strongly dissected relief classes.

Finally, in compartment 4, at the top of the mountain, the relief is strongly dissected for all proposals (photograph c).

Figure 11 – Topographic profile (A-B), in which photographs obtained in the field and the product of the three dissection mapping proposals are presented



Source: Prepared by the authors, 2020.

MANTOVANI, J. R.; BUENO, G. T.

Final considerations

This study proposed a methodology of easy execution and visualization to map relief dissection without the need for interference from the decision-maker. The advantage of the proposed methodology is its applicability in any geographic region regardless of the database used, since the classification of variables does not follow the same thresholds as the values proposed in the Ross' dissection matrix (1994) (Figure 2-a), and can map areas with any altimetric interval. Based on the bivariate legend, considering the results obtained, we could map and distinguish the variables *incision of the valleys* and *interfluvial dimension* distributed throughout the study area.

The proposal of the bivariate legend to map relief dissection proved efficient, since precision and fidelity were satisfactory when compared with the real aspects of the terrain. The products obtained, added to the profiles, photos and graphs, showed spatial correlation with the other mappings performed by proposals existing in the Brazilian literature. The three proposals presented greater correspondence, especially where the dissection is "very strong", in the steep and rugged areas of the park and in adjacent areas with steep slope.

We performed spatial analysis of the mappings on a scale that allowed to dynamically see a geographical area, which is important mainly because it was performed in a National Park with tourist activities and an environment with many economic activities. Although it was not the focus of this study, this type of analysis can support planning measures to improve preservation and control in the park, especially risk areas and in areas susceptible to erosive processes and landslide.

The results obtained in the area and analyzed by topographic profile, photographs and correlation with the Kernel map on each surface show the reliability of the proposed methodology. Future studies should use images of digital elevation models (DEM) or terrain models with better spatial resolution, especially for application at more detailed scales, in addition to primary and secondary cartographic products that help analysis and interpretations. To complement the analysis of the results, we also suggested the inclusion of other significant variables for relief dissection, such as lithological, structural and climatic variables.

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Authors' Contribution

José Roberto Mantovani: geographic database collection and structuring, application of methodologies available in the literature, implementation of the methodology proposed in the study, geoprocessing and digital cartography, maps and figures, data analysis and textual review.

Guilherme Taitson Bueno: evaluation and structural systematization of the text and comparison of the methodology with others available in the Brazilian literature, evaluation of the results and general review of the text and figures.

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