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ORIGINAL ARTICLE

Analysis of quantitative methods for geodiversity in Chapada Diamantina, Bahia, Brazil

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Abstract:

The concept of geodiversity has been developed by geoscientists since 1990 in different lines of research such as territorial and patrimonial planning, tourism and the dissemination of knowledge. However, little progress has been made in mapping and quantifying geodiversity. Thus, there are still gaps about the functionality of these graphics products. In order to contribute to these discussions, the aim of this research was to evaluate geodiversity quantification models in Chapada Diamantina National Park and municipality of Morro do Chapéu. The methods Serrano and Ruiz – Flaño and Pereira et al. were chosen for comparison. After choosing the criteria to compare as the choice of variables pertaining to each method, data processing was performed in a geographic information system. Maps with geodiversity indexes and frequency charts were generated. Finally, these products were analyzed using statistical methods and evaluated in the field. In both proposals for quantifying geodiversity, methodological limitations were found, which interfere with the purpose for which the index was created.

Keywords: geodiversity index; models in the Geosciences; landscape quantification.

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1. Introduction

Changes in environmental systems caused by interventions in the primitive landscape bring damage to the ecological balance and the maintenance of life. In this context, the academic environment began to develop and disseminate concepts that supported the development of methods focused on environmental issues such as the preservation of the natural heritage. Environmental issues, especially those related to the preservation of biodiversity, have gained importance in the media and government agencies since the RIO - 92.

Despite the greater popularization of the term biodiversity, which for decades has had a theoretical-methodological framework already systematized in the scientific community, the geodiversity neologism was also designated. The concept of geodiversity was initially thought of as analogous to that of biodiversity (Serrano and Ruiz-Flaño 2007; Carcavilla et al. 2008; Gray 2013). It can be defined as: The natural range (diversity) of geological (rocks, minerals, fossils), geomorphological (landforms, topography, physical processes), soil and hydrological features. It includes their assemblages, structures, systems and contributions to landscapes (Gray 2013). There are other definitions of geodiversity such as Sharples (1995); Johansson et al. (1999); Stanley (2000); Nieto (2001); Kozlowski (2004); Serrano and Flaño (2007). Although there are disagreements about the concept, geological, geomorphological elements and soils are common to all and are the most relevant structural elements of the landscape (Forte 2018).

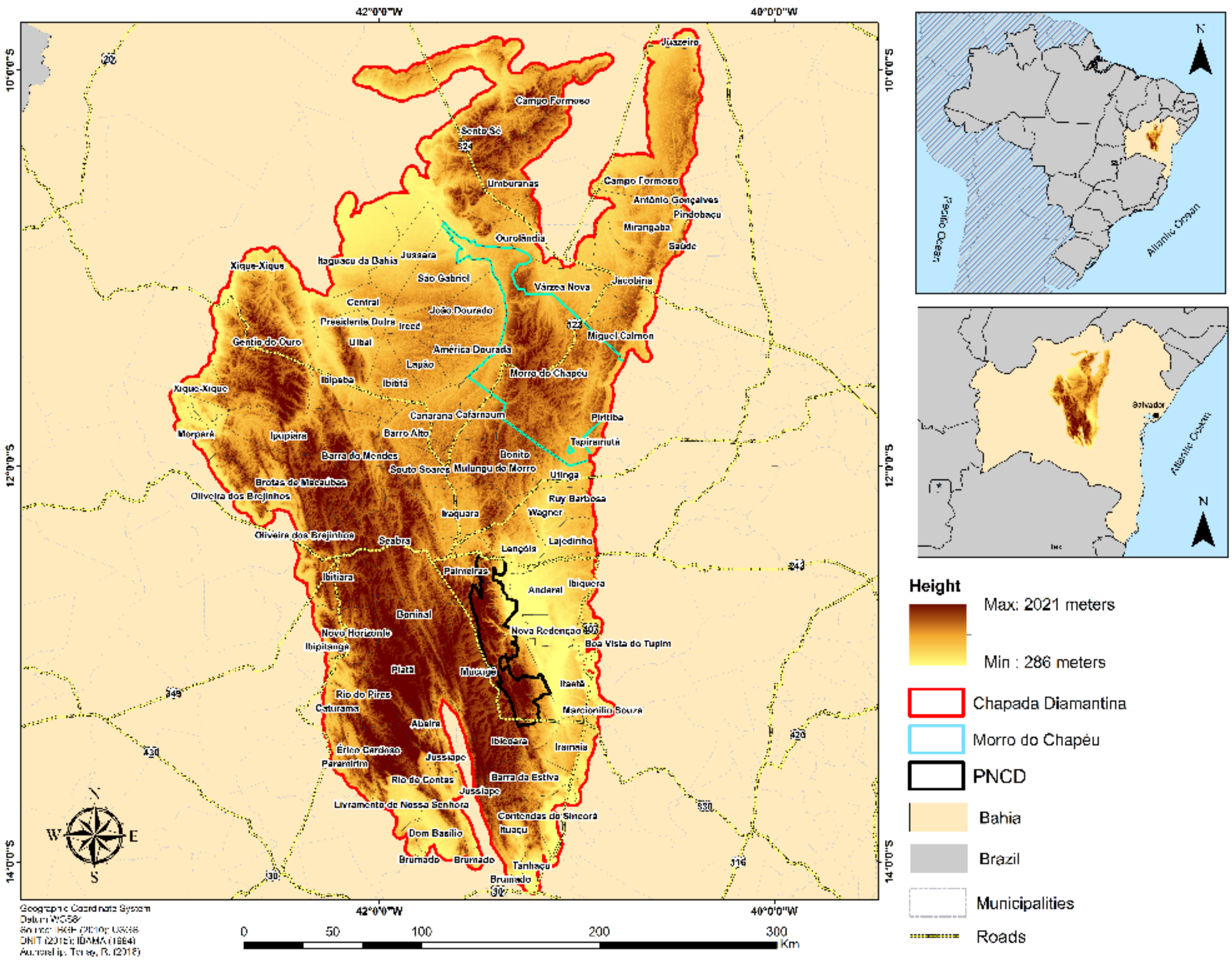
On the one hand, qualitative methods were developed for the inventorying and valuation of geomorphological and geological heritage such as those of Rivas et al. (1997); Panizza (2001); Bruschi and Cendrero (2005); Pereira et al. (2007); Reynard (2007); Zouros (2007) and Garcia – Cortes and Urqui (2009). These proposals have as a common characteristic, not encompassing different levels of coverage, but mainly of abiotic-geological type (Zwolinski 2018).

On the other hand, there are lines of research that aim to evaluate geodiversity in an integrated manner using direct and indirect methods (Manosso and Ondicol 2012), quantitative or qualitative-quantitative, (Zwolinski 2018) whose main researchers are: Xavier da Silva (2001); Kozlowski (2004); Serrano and Ruiz - Flaño (2007); Carcavilla et al. (2008); Benito-Calvo et al. (2009); Zwolinski (2009); Hjort and Luoto (2010, 2012); Ruban (2010); Pereira et al. (2013); Silva et al. (2015); Melelli (2014); Manosso and Nobrega (2016); Argyriou et al. (2016); Araújo and Pereira (2018); Santos et al. (2019) and Forte (2018). In practice, the methods of geodiversity assessment and quantification propose new tools for landscape analysis, help in decision-making on topics such as conservation of the abiotic environment, ecosystem services, territorial management, and the study of the relationships between abiotic and biotic elements.

Thus, although the number of works on geodiversity quantification has been intensifying (Ruchkys et al. 2017), there are still gaps to be filled regarding the applicability and replicability of the methods in different areas, and the compatibility of the variables (Melelli 2014). At different cartographic scales and the choice of the elements that make up the abiotic environment and if they could be analyzed together (Gray 2013). In this context, this work aims to evaluate and compare models of geodiversity quantification based on geoprocessing techniques in the pilot areas: Chapada Diamantina National Park and Municipality of Morro do Chapéu, both are localized in the central region of the state of Bahia in Brazil.

2. Study Area, Materials and Methods

The methods were applied in two areas with different surfaces, but with similar physiographic contexts, Chapada Diamantina National Park and municipality of Morro do Chapéu (Figure 1).



Source: Roger Torlay (2018)

Figure 1: Location of municipality of Morro do Chapéu and Chapada Diamantina National Park highlighted in black and cyan, respectively. Besides main access roads and municipalities of the study areas in Chapada Diamantina with their respective altitudes.

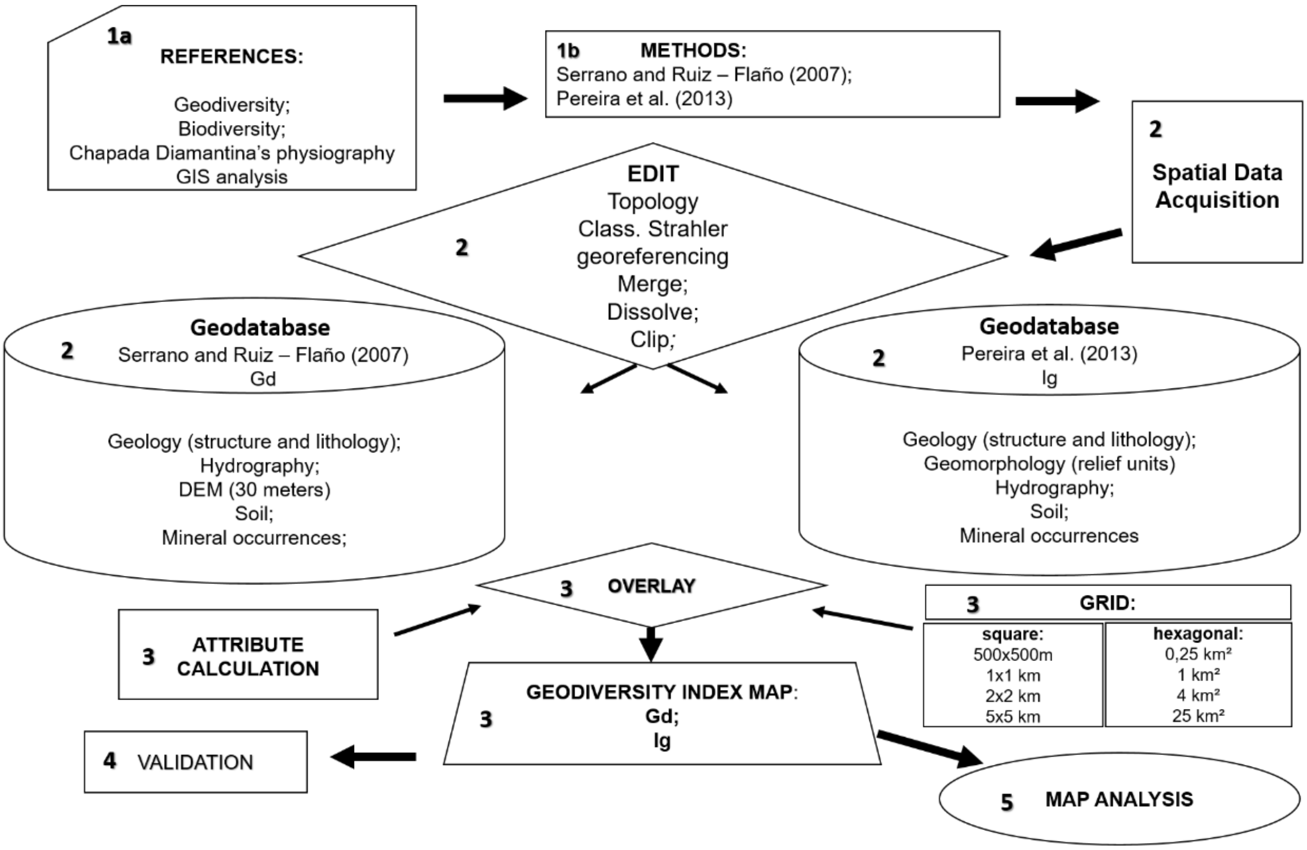
Chapada Diamantina (Figure 1) encompasses the northern part of the Espinhaço Range, a set of disjoint mountains that extends from the state of Minas Gerais, towards the north, until reaching the São Francisco River (Misi and Silva 1996). This region occupies an area of approximately 65.000 km², in which approximately 75 municipalities are located. The region is characterized by a set of mountainous reliefs, plateaus, karst systems and sedimentary basins, developed essentially in rocks of sedimentary and metasedimentary nature, which are stratigraphically grouped in the Rio dos Remedios, Paraguaçu, Chapada Diamantina and Una Groups (Pereira 2010).

Moreover, Chapada Diamantina is a division of the São Francisco valley to the west and the coast to the east, and is geographically divided into several mountain ranges, such as Rio de Contas, Bastião, Mangabeira and Sincorá. In the latter, located east of Chapada Diamantina, is the Chapada Diamantina National Park (PNCD).

This work was carried out in 5 stages. The summary of the steps is illustrated and numbered in the methodological flowchart shown in Figure 2.

In the first stage a bibliographic survey (**1a**) was made, and the choice of methods (**1b**) for geodiversity quantification. The criteria for choosing the methods were: conceptual and practical coherence, pioneering methodological development, methodological clarity and relevance to the scientific community (high number of citations and high impact factor). So, the methods that best met these criteria were Serrano and Ruiz - Flaño (2007) and Pereira et al. (2013).

The method of Serrano and Ruiz - Flaño (2007) had the largest number of citations, so it was used as a theoretical basis for most works on geodiversity assessment and quantification. In summary, the generated index, called “Gd”, consists of the sum of physical elements present in a given area (geological, geomorphological, hydrological and pedological) multiplied by the roughness of the relief.



Source: Roger Torlay (2018)

Figure 2: Methods procedure used to quantify geodiversity and analyse in the municipality of Morro do Chapéu and Chapada Diamantina National Park.

The method of Pereira et al. (2013) is derived from Serrano and Ruiz - Flaño (2007) method, however, instead of using territorial unit-based polygons as a municipality or region and a formula, it proposes the use of regular grids to calculate the geodiversity index or “Ig”, from the sum of subindices using as abiotic elements like structure, rock types, geomorphological units, soils, hydrography, mineral and fossiliferous occurrences.

Geodata acquisition and vector editing (2). At this stage the geographic databases were constructed with the following variables: geology, geomorphology, hydrography, pedology and mineral occurrences for the municipality of Morro do Chapéu (Rocha and Costa 1995), and the Chapada Diamantina National Park (CPRM 1994) in two cartographic scales from 1: 100.000 and 1: 1.000.000 (CPRM 2006).

So that there was no repetition in the geodiversity attribute count (sum), each feature class was joined, thus becoming “1”. In the case of hydrography, each hierarchical class (Strahler 1957) was assigned a value of “1”.

Application of the methods (3). With the edited data, processing started on the Arcgis® package. For both methods, the same geodiversity elements based on Pereira et al. (2013): geomorphological units, lithology, structure, hydrography, first order soils, mineral occurrences of mineral exploration, such as diamond mines. The fossil occurrences were not computed for lack of data.

In the modeling based on Serrano and Ruiz - Flaño (2007), after generating the data using overlay tool was calculated by the original formula (1) and the formula without the roughness variable "R" (2). For roughness calculation, the slope of the terrain was first generated from the digital model elevation DEM from Japan Aerospace Exploration Agency, with a pixel size of 30 meters. After that, roughness values derived from the slope classes were determined according to Serrano e Ruiz – Flaño (2007).

$$Gd = EgR/lnS \tag{1}$$

$$Gd = Eg/lnS \tag{2}$$

Equation (1) and (2) shows: Gd = Geodiversity Index; Eg = Number of physical elements (geomorphological, hydrological, soil) different existing in the unit; R = Roughness coefficient of the unit; S = Surface of the unit (km^2).

Finally, with the results of the calculations, maps and graphs were prepared. To improve visualization, geodiversity indices were grouped into 5 class ranges using natural breaks (Jenks 1967) with the following nomenclatures: very low, low, medium, high and very high. This interval classification was made for both the Serrano and Ruiz - Flaño (2007) model maps and for the Pereira et al. (2013), which will be seen below.

For the definition of grid sizes, the effective scale and minimum mappable area were first calculated (Forbes et al. 1982), it was defined that for scale 1: 100.000 the smallest polygon that would appear on the map was 0.25 km^2 and for scale to the millionth 25 km^2. Thus, regular hexagonal and square grids were generated from the minimum mappable area in the two worked scales (0.25 km^2 and 25 km^2) and also intermediate sizes such as 1 km^2 and 4 km^2. Hexagon grids were generated from a script adapted from the tool that creates Thiessen polygons in the Arcgis® software.

After making the grids, they were overlapped in each theme (rocks, geomorphological units, structure, hydrography, mineral occurrences and soils), resulting in sub-index maps. After this step, the number of features found of the themes within each cell was calculated. The resulting sum value corresponds to the geodiversity index (Ig). These same procedures were done to scale to the millionth and in both pilot areas.

The fourth **(4)** step consisted of **validating** the map information against the reality in the **field**. Sixteen stopping points were predefined in the test areas (PNCD and Morro do Chapéu whose objective was to cross the widest range of different values of the geodiversity index in order to visually interpret the values.

Finally, an **analysis of the methods** was performed **(5)**. For the model based on Serrano and Ruiz - Flaño (2007) the indices generated between equations (1) and (2) were compared in both study areas mapped on the 1: 100.000 scale. It is noteworthy that no map of the geodiversity index was generated on the millionth scale because this method was designed for medium and local scales.

From the maps generated based on the method Pereira et al. (2013) was tried to compare by statistical analysis the indices by grid types, that is, square grid versus hexagonal grid and at different scales (1: 100.000 and 1: 1.000.000). Spatial analysis between types and grids and cartographic scale calculations were made using the difference between maps and the Kendal correlation (tau).

3. Results and discussions

3.1. Serrano and Ruiz – Flaño (2007) applied method

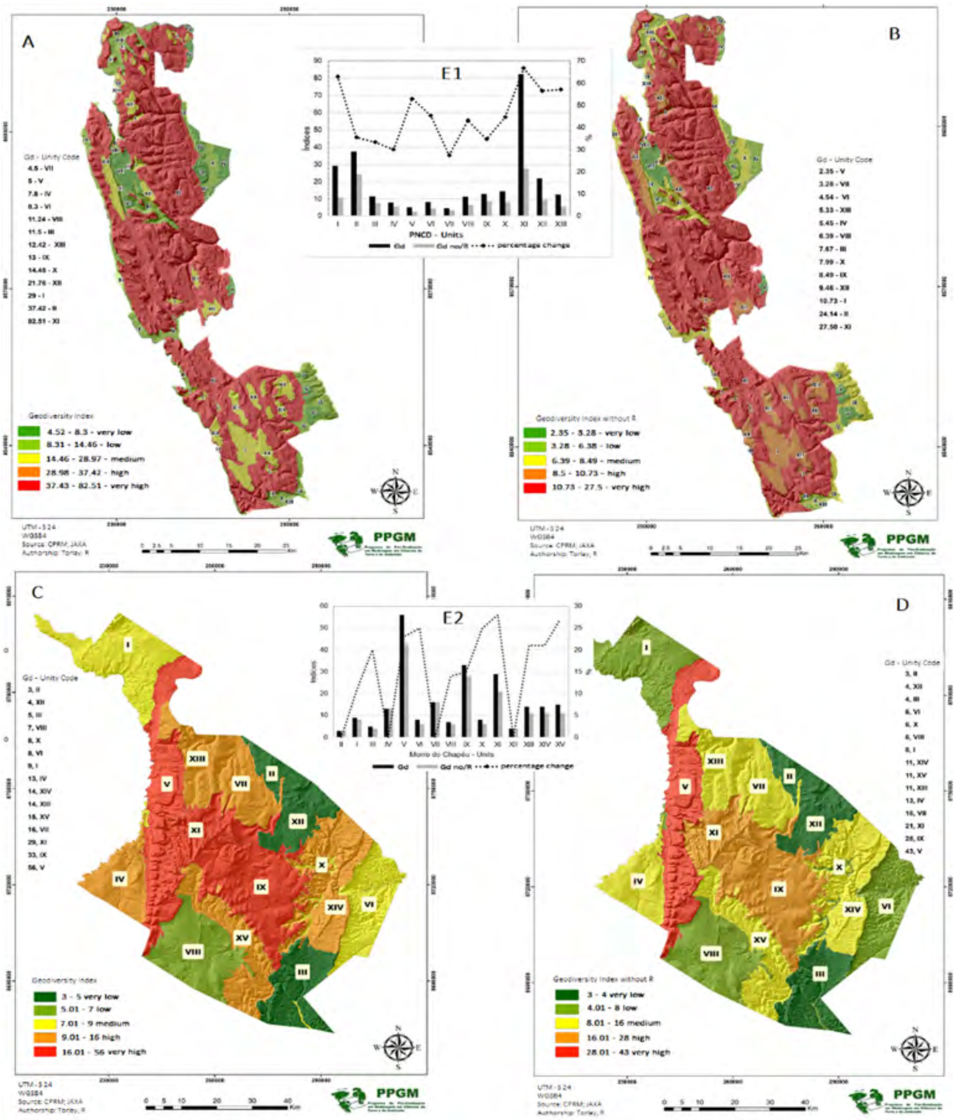
The results obtained with the application of the Serrano & Ruiz - Flaño (2007) method and its variation (without the roughness coefficient) are shown in table 1. And as a product, geodiversity maps with its variants (Figure 3 - A, B, C and D) and the graphs comparing the use of the roughness variable (Figure 3 - E1 and E2).

Table 1. Chapada Diamantina National Park and Morro do Chapéu: calculations for geodiversity indices.

PNCD Units	code	Eg	lnS	R	Gd	Gd w/ R	area km²	area %
Depressões abertas na superfície por processos erosivos	I	29	3	2.7	29	10.7	15	0.98
Encostas dos patamares	II	5	0.2	1.5	37	24	1,2	0.08
Escarpas frontais e depósitos de tálus	III	34	4	1.5	11	7.7	84	5.52
Interflúvios tabulares ou semitabulares	IV	20	4	1.4	8	5.4	39	2.58
Morros de topo arredondado	V	7	3	2.1	5	2.3	19.5	1.28
Patamares de superfície ondulada com frequentes afloramentos de rocha	VI	8	1,7	1.8	8	4.5	5.83	0.38
Patamares de superfície ondulada com vales encaixados e drenagem densa	VII	10	3	1.4	4.5	3.3	21	1.38
Patamares estruturais de fundo de alvéolo formados por erosão diferencial	VIII	6	0.9	1.7	11	6.4	2.56	0.17
Patamares rochosos com ausência de recobrimento detrítico superficial	IX	36	4	1.5	13	8.5	69	4.54
Planícies fluviais aluviais	X	27	3	1.8	14.5	8	29	1.92
Superfície estrutural de relevo irregular e ruiniforme	XI	192	7	3	82.5	27.5	1075	70.45
Superfície estrutural de relevo plano	XII	47	5	2.3	22	9.46	143	9.40
Superfícies amorreadas de fundo de alvéolo talhadas por erosão diferencial	XIII	16	3	2.3	12	5.33	20	1.32
Total	---	437	7.33*	2**	119	59.6	1,526	100%

Morro do Chapéu Units	code	Eg	lnS	R	Gd	Gd w/ R	area km²	area %
Baixada do Rio Jacaré	I	49	5	1.1	9	8	529	9
Baixada do Rio Salitre	II	17	6	1	3	3	170	3
Chapada de Duas Barras	III	24	6	1.2	5	4	377	6
Chapada de Ouricuri	IV	73	6	1	13	13	305	5
Encosta ocidental	V	281	7	1.3	56	43	712	12
Patamar dissecado de Dias Coelho	VI	34	6	1.4	8	6	392	7
Pedimentos do Rio Salitre	VII	93	6	1	16	16	365	6
Planalto de Lagoinha	VIII	40	6	1	7	6	506	8
Planalto do Morro do Chapéu	IX	186	7	1.1	33	28	754	13
Planícies fluviais	X	24	4	1.3	8	6	52	1
Superfície serrana	XI	122	6	1.3	29	21	315	5
Tabuleiro de Flores	XII	20	5	1	4	4	230	4
Tabuleiro rampeado	XIII	60	6	1.4	14	11	260	4
Vale do Rio Ferro Doido	XIV	67	6	1.2	14	10	609	10
Vão dos Córregos	XV	65	6	1.3	15	11	417	7
Total	...	1155	8.6*	1.2**	234	193	5,993	100%

Table note: Eg = Sum of the different features of geodiversity (soils, geology, morpho-sculptural units, mineral occurrences, water bodies,; lnS = Neperian logarithm of the area (km²); R = roughness coefficient; Gd = geodiversity index; Gd w / R = the geodiversity index without the roughness variable. * ln of the total area. ** arithmetic mean calculated for the weighted averages of the units.

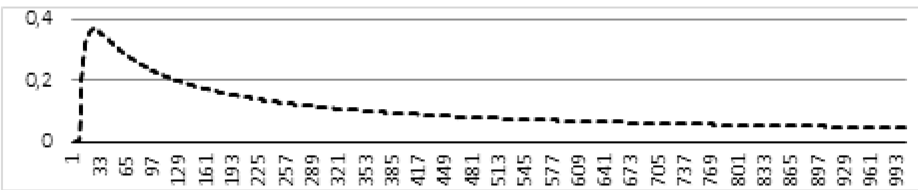


Source: Roger Torlay (2018)

Figure 3: Map of the Chapada Diamantina National Park and Morro do Chapéu geodiversity index (A, C); Map of the geodiversity index without roughness (B, D); Graph of the variation between indices (E1, E2).

The indexes (Gd) calculated in the PNCD geomorphological units ranged from 4.5 in VII to 82.5 in XI. It is noted on the map (Figure 3 - A) that the “very high” class coincided with the unit with the largest area (70% of the total area). However, unit II, the smallest area (0.08% of the total area), obtained a value of 37.4. Thus, the second unit with the highest geodiversity index.

The same discrepancy in values (small areas with a high index) was found in a paper by Serrano and Ruiz-Flaño (2007). Although the use of natural logarithms had the function of smoothing abrupt values, when the values of area (S) is less than or equal to “e” (Euler number), they generate an overvaluation of the index. Figure 4 illustrates this problem.



Source: Roger Torlay (2018)

Figure 4: Logarithmic function: y = ln (x) / x.

In Morro do Chapéu there were no discrepancies in the value of the index in relation to the area of the unit. However, when comparing the variation of R in the two pilot areas, it can be seen that in the PNCD the R enhances the final result of the index. Moreover, in Morro do Chapéu this variable does not interfere substantially in the result. This is due to the method to obtain the roughness. Even using the weighted average of the slopes for each unit in order to transform the slope intervals into R, the unit measurement interferes with the result. That is, the larger the unit, the greater the smoothing of slope averages. The reverse also occurs.

Serrano and Ruiz-Flaño (2007), state that the parameter R, should be studied more thoroughly and be tested in areas with slope variability. Pereira et al. (2013) state that, depending on the area to be applied to the index, the result can be overestimated. Hjort and Luoto, (2010) did not use the roughness due to the low altimetric variation of their test area. It can still be said that this variable brings redundancy, of a geomorphological order, to the composition of the model.

Another problem that may arise in this model is when there are Units of the same class without contiguity in the territory, the final value may not be proportional in relation to the Unit with continuous territory.

In addition to the factors mentioned above, the choice of physical components found in the maps of geology, geomorphology and soils, which form "Eg" can influence the result of the index. For example, features represented as points (mineral resources) or lines (hydrography, faults and geological fractures) increase the index values disproportionately in relation to the features represented by polygons (soils, lithology and landforms).

In theory, this model should be able to compare geodiversity between different areas, but everything indicates that it is not possible.

3.2. Pereira et al. (2013) applied method

Geodiversity maps were generated from the sub-indices in the scales 1: 100.000 and 1: 1.000.000 using square and hexagonal grids in the sizes 0.25 km², 1 km², 4 km² and 25 km².

The variations in the indices for the different study areas extracted by the different grids are shown in table 2. On the millionth scale, the lowest values exceed the lowest values of the indices generated with data on a 1: 100.000 scale. This shows how much the cartographic scale influences the geodiversity index. However, when comparing the maximum and minimum values of the indices at different scales, there seems to be no proportion in relation to the degree of generalization of the map. Therefore, even though the millionth scale has 10 times less levels of detail than 1: 100.000, there was a difference of 10 to 45 percent in the amplitude of these indices.

Table 2: Variations in geodiversity indices (maximum and minimum) extracted by hexagonal, square grids on the 1: 100.000 and 1: 1.000.000 scales.

Tipe	Size	Index - PNCD	Index - Morro do Chapéu
hexagonal to millionth	0,25 km²	3 - 6	1 - 7
	1 km²	3 - 8	1 - 9
	2 km²	3 - 9	1 - 9
	5 km²	4 - 15	4 - 15
square to millionth	0,25 km²	3 - 7	3 - 8
	1 km²	3 - 9	3 - 10
	2 km²	3 - 11	3 - 10
	5 km²	3 - 17	4 - 16
Hexagonal	0,25 km²	2 - 11	3 - 11
	1 km²	2 - 13	3 - 15
	2 km²	2 - 18	3 - 18
	5 km²	4 - 25	3 - 31
square	0,25 km²	1 - 11	3 - 11
	1 km²	2 - 12	3 - 15
	2 km²	2 - 18	3 - 18
	5 km²	3 - 26	3 - 28

Table 3 and Table 4 show the Kendal correlation matrices. From them, it is possible to analyze the degree of self-similarity between pairs of maps with different scales, sizes and types of grids in the two pilot areas.

Then, as the grid size increases or decreases in both study areas, the index value changes gradually until there is no correlation between the indexes ($\tau = 0$). For example, index values in a 0.25 km² square grid on the 1: 100.000 scale with a 1 km² square grid have 60% correlation, that is, the indexes are correlated, although low, and can be considered above 7 for values with strong correlation. If you compare the same square grid map of 0.25 km² with another of 25 km², the indices are 24% (weak spatial correlation). When comparing grids of the same area, but with data at different scales such as 1: 100.000 and 1: 1.000.000, there is little or no special correlation, and there are no patterns such as the gradual sequence of values according to combinations of grid sizes. Therefore, the choice of the cartographic scale of the variables also interferes with the value of the geodiversity index.

Table 3: Kendall correlation matrix between maps of the geodiversity index: Chapada Diamantina National Park.

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
A	1															
B	0,53	1														
C	0,31	0,44	1													
D	0,12	0,18	0,36	1												
E	0,26	0,25	0,21	0,07	1											
F	0,21	0,26	0,26	0,09	0,68	1										
G	0,16	0,20	0,20	0,09	0,47	0,65	1									
H	0,06	0,08	0,13	0,05	0,30	0,40	0,23	1								
I	0,71	0,47	0,29	0,11	0,23	0,19	0,15	0,06	1							
J	0,49	0,51	0,36	0,12	0,26	0,26	0,21	0,12	0,47	1						
K	0,33	0,45	0,48	0,30	0,22	0,26	0,28	0,16	0,32	0,41	1					
L	0,12	0,18	0,33	0,47	0,04	0,05	0,04	0,03	0,11	0,13	0,27	1				
M	0,24	0,24	0,20	0,07	0,76	0,62	0,45	0,29	0,22	0,26	0,22	0,04	1			
N	0,22	0,26	0,26	0,10	0,65	0,73	0,58	0,38	0,21	0,32	0,27	0,06	0,62	1		
O	0,16	0,20	0,23	0,11	0,47	0,61	0,68	0,50	0,15	0,24	0,26	0,05	0,45	0,27	1	
P	0,07	0,08	0,17	0,11	0,27	0,36	0,47	0,63	0,07	0,16	0,17	0,11	0,27	0,36	0,47	1

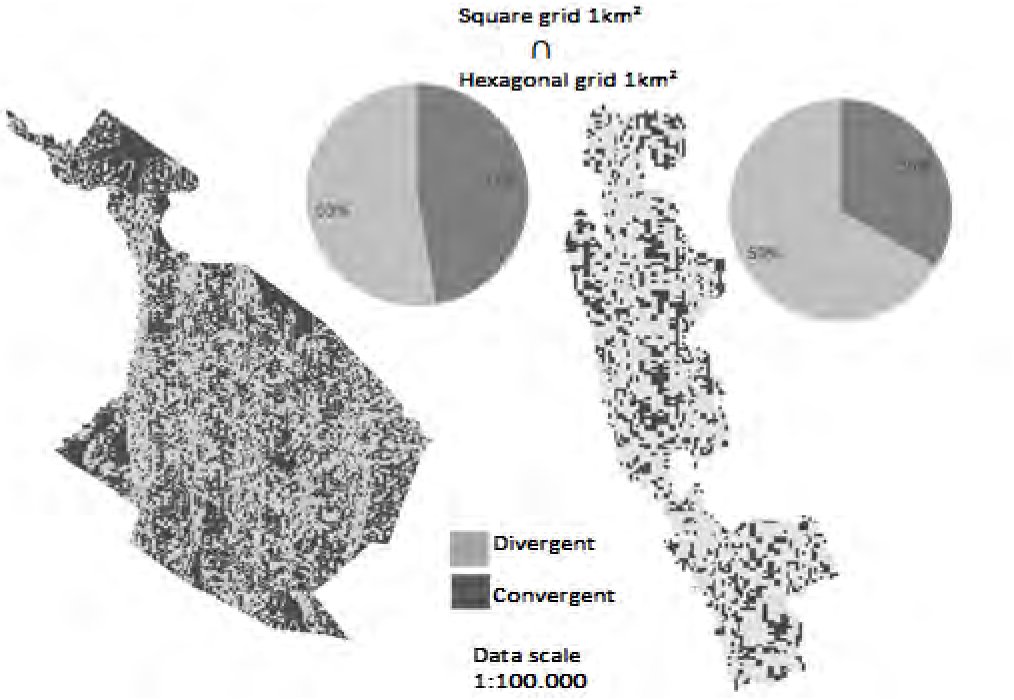
Table note: each letter represents a map of the geodiversity index generated from the square and hexagonal grid and with data in the scales 1: 100.000 and 1: 1.000.000. Thus: **A** = 0.25 km² square grid (1: 100.000); **B** = square grid 1 km² (1: 100.000); **C** = square grid 4 km² (1: 100.000); **D** = 25 km² square grid (1: 100.000); **E** = 0.25 km² square grid (1: 1.000.000); **F** = square grid 1 km² (1: 1.000.000); **G** = square grid 4 km² (1: 1.000.000); **H** = 25 km² square grid (1: 1.000.000); **I** = hexagonal grid 0.25 km² (1: 100.000); **J** = hexagonal grid 1km² (1: 100.000); **K** = hexagonal grid 4 km² (1: 100.000); **L** = hexagonal grid 25 km² (1: 100.000); **M** = hexagonal grid 0.25 km² (1: 1.000.000); **N** = hexagonal grid 1 km² (1: 1.000.000); **O** = hexagonal grid 4 km² (1: 1.000.000); **P** = hexagonal grid 25 km² (1: 1.000.000). Correlated indexes were highlighted.

Table 4: Kendall correlation matrix between maps of the geodiversity index: Morro do Chapéu.

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
A	1															
B	0,65	1														
C	0,44	0,60	1													
D	0,24	0,35	0,51	1												
E	0,13	0,20	0,20	0,13	1											
F	0,22	0,26	0,25	0,16	0,68	1										
G	0,21	0,27	0,30	0,21	0,47	0,63	1									
H	0,14	0,18	0,23	0,21	0,26	0,34	0,48	1								
I	0,77	0,60	0,42	0,24	0,18	0,22	0,21	0,14	1							
J	0,62	0,70	0,55	0,34	0,21	0,26	0,26	0,17	0,59	1						
K	0,45	0,57	0,66	0,51	0,20	0,27	0,30	0,24	0,43	0,56	1					
L	0,26	0,37	0,53	0,68	0,13	0,17	0,21	0,21	0,26	0,36	0,52	1				
M	0,20	0,21	0,19	0,12	0,71	0,60	0,44	0,25	0,20	0,21	0,20	0,14	1			
N	0,24	0,27	0,25	0,17	0,62	0,70	0,56	0,34	0,23	0,27	0,27	0,18	0,60	1		
O	0,23	0,29	0,30	0,24	0,46	0,58	0,68	0,48	0,22	0,29	0,32	0,24	0,44	0,57	1	
P	0,14	0,19	0,24	0,26	0,27	0,34	0,47	0,60	0,13	0,18	0,25	0,23	0,26	0,35	0,49	1

When comparing the degree of self-similarity between hexagonal and square grids in different sizes, it was not possible to find conclusive answers about the performance of one type of grid in relation to another to calculate the indexes.

In Figure 5 a self-similarity test is shown: the difference between indices generated by square x hexagonal grids. Thus, in Morro do Chapéu there was a similarity of 47%. In the Chapada Diamantina National Park, 30% convergence between maps with the same grid size. Therefore, using the types of square or hexagonal grid can influence different results. With the tests carried out here, we do not have the necessary support to affirm which grid is better to quantify geodiversity. Thus, it can only be said that the hexagonal grid provides better aesthetic visualization on the map.



Source: Roger Torlay (2018)

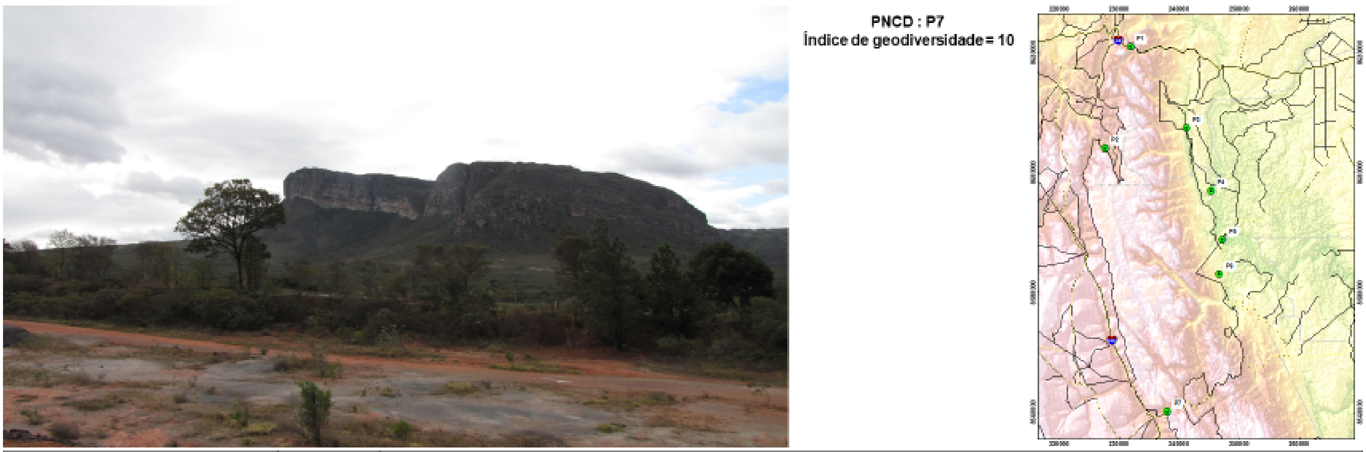
Figure 5: Calculation of the difference in geodiversity indexes generated from hexagonal and square grids with 1 km² in size on the 1: 100.000 scale.

Other cartographic procedures that can help in choosing the grid is to understand the relationship between features represented by points, lines and polygons with the grid type where feature values are added, which result in a synthesis cartography. Thus, the understanding of the form factor, or form complexity index (S), which seeks to describe the general geometry of polygons in thematic maps, calculates the relationship between perimeter and area of each polygon (Hole 1978). In addition, as a way of reducing the ambiguity in the choice of grids to generate the geodiversity index, Pires (2018) suggests: using the effective scale calculation of Forbes et al. (1982) to define the grid size proportional to the scale available data: i) generate grids with sizes lower and higher than the created grid; ii) Generate the geodiversity index maps; iii) Calculate the arithmetic mean between the maps; and iv) generate a single synthetic map. This done, the relevance of the calculated average in relation to the universe should be tested. For this, the standard deviation of the data can be observed and use tests such as the Gamma coefficient and the uncertainty test.

3.3 Validation of Maps on the Field

The field evaluation did not aim to judge the official mappings, using them as a true model. In addition, as the main premise for this task, it focused on the analysis of the representativeness of geodiversity and its spatialization from the application of the methods.

Figure 6 shows one of the 16 visitation points where one of the highest values of the geodiversity index in the study areas was found. In this area, geological faults were found, 3 types of rocks, 3 types of soil, 2 types of geomorphological units and water bodies, totaling 10 natural features, that is, a geodiversity index equal to 10.



Elementos abióticos	Eg	Descrição
Ocorrência mineral	0	
Hidrografia	1	Quarta ordem
Estrutura geológica	1	
Solos	3	Solo aluvial/ Podzol/ solos Litólicos.
Litologia	3	Diamictitos, argilitos, siltitos, arenitos finos e pelitos com seixos pingados, relacionados a geleiras (glaciação e deglaciação)/ Cascalhos, areias e argilas dos aluviões recentes/ Argilas e areias derivadas do Grupo Paraguaçu e da Formação Tombador
Unidades geomorfológicas	2	Patamares rochosos com quase total ausência de recobrimento detrítico superficial/ Planícies fluviais aluviais/ Superfície estrutural de relevo irregular e ruiniforme
Observações: Mucugê, vista sentido noroeste. Área com alta riqueza de elementos abióticos, principalmente tipos de solos, litologia e unidades de relevo.		

Source: Roger Torlay (2018)

Figure 6: Visiting point with geodiversity index = 10 in the National Park of the Chapada Diamantina.

Figure 7 shows the visitation point with the lowest value of the geodiversity index. In this area, 1 type of rock, 1 type of soil and 1 geomorphological unit were found, totaling 3 natural features, that is, a geodiversity index equal to 3.

After the fieldwork, it was found the difficulty of perceiving the diversity of physical features using maps based on the method of Serrano and Ruiz-Flaño, (2007). For the maps with the indexes extracted from grids, the values of the indexes generated were compatible with the reality in the field. However, it was noted that the smaller the grid, the greater the chances of the values being smaller due to the scope, especially when the abiotic elements have their features represented by points and lines. In addition, there is the aggravating geographic position of the grid, which depending on its location may include or exclude elements of geodiversity. This is because the grid is generated by default in the software from the polygon surrounding the study area. In larger grids, such as those of 25 km², the perception in loco of the physical elements is lost, due to the excessive scope. Therefore, among the maps with different grids taken to the field, the one with the best performance to understand the geodiversity was the 1 km² grid.

Elementos abióticos	Eg	Descrição
Ocorrência mineral	0	
Hidrografia	0	
Estrutura geológica	0	
Solos	1	Areia Quartzoza
Litologia	1	Calcário cinza claro
Unidades geomorfológicas	1	Chapada de Ouricuri
Observações: Monotonia altimétrica, pouca variação de elementos abióticos.		

Source: Roger Torlay (2018)

Figure 7: Visiting point with geodiversity index = 3 in Morro do Chapéu.

4. Conclusion

In view of the arguments presented, the main conclusions of this work and the resulting recommendations were scored:

a) For areas with strong slope variations, the inclusion of the roughness coefficient contributes to determining the values of the geodiversity index (Gd). In flat areas with a slope lower than 5° degrees, the coefficient of roughness does not affect the final value. Further research that uses indirect methods to assess geodiversity must be developed, as well as testing other ways to extract the roughness of the landscape;

b) A paradox was found in the formula for the geodiversity index of Serrano and Ruiz-Flaño (2007) in relation to the use of ln as the denominator. It is concluded that, areas smaller than the Euler number generate hyper valued indexes, and depending on the thresholds in the logarithmic scale, territories with size variation between Units may have the geodiversity index overestimated or underestimated. Therefore, this limitation of the studied method sheds light on the importance of auditing the data before incorporating them into the modeling;

c) The effective scale calculation should be used as a parameter in relation to the minimum grid size. It is also suggested to use arithmetic media of values of the geodiversity index strained by different grid sizes. Therefore, it is necessary to advance in studies that aim to create cartographic parameters that involve the scales of the base maps with the maximum grid sizes.

d) The indices generated from cartographic bases to the millionth need further studies. It should be sought what elements and levels of geodiversity should be included in the model for small scales;

e) As it was found that the physical attributes represented on the map by points overvalue the composition of the index, it is recommended to use the elements represented by points in a superimposed way on the geodiversity map or to create an index based on weighted values.

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Roger Torlay contributed to the elaboration and consolidation of all phases of the manuscript under the guidance of Marjorie Csekö Nolasco and Paulo de Tarso Amorim de Castro.

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