Journal of Maps

ISSN: 1744-5647 (Online) Journal homepage: www.tandfonline.com/journals/tjom20

# Representation of relief by geomorphometric archetypes: a ‘new’ vision of geomorphological mapping in Brazil

Gervásio Barbosa Soares Neto, Edson Eyji Sano, Vinicius Vasconcelos, Karla Maria Silva Faria & Eder De Souza Martins

**To cite this article:** Gervásio Barbosa Soares Neto, Edson Eyji Sano, Vinicius Vasconcelos, Karla Maria Silva Faria & Eder De Souza Martins (2026) Representation of relief by geomorphometric archetypes: a ‘new’ vision of geomorphological mapping in Brazil, Journal of Maps, 22:1, 2626113, DOI: 10.1080/17445647.2026.2626113

**To link to this article:** https://doi.org/10.1080/17445647.2026.2626113

JOURNAL OF MAPS
2026, VOL. 22, NO. 1, 2626113
https://doi.org/10.1080/17445647.2026.2626113



# Representation of relief by geomorphometric archetypes: a 'new' vision of geomorphological mapping in Brazil

Gervásio Barbosa Soares Neto [a], Edson Eyji Sano [b], Vinicius Vasconcelos [c], Karla Maria Silva Faria [d] and Eder De Souza Martins [b]

[a]Instituto Federal de Brasília, Brasília, Brazil; [b]Embrapa Cerrados Research Center Embrapa Cerrados, Planaltina, Brazil; [c]Departamento de Geografia, Universidade de Brasília, Brasília, Brazil; [d]Federal University of Goiás, Institute of Socio-Environmental Studies, Goiânia, Brazil

**ABSTRACT**
This study presents a geomorphological map of Brazil based on geomorphometric parameters. The lack of standardized relief representation highlights the need for objective delineation of relief units using measurable morphometric characteristics. Available relief and slope were combined with a geomorphometric approach based on mathematical modelling to identify predominant landform archetypes and define metric relief classes consistent with observed terrain conditions. A classification system dividing Brazil into fifteen relief classes was developed, including plains, fluvial terraces, alluvial fans, depressions, plateaus, scarps, sierras, hills and low hills. Each class was associated with characteristic slope forms. The resulting geomorphological map improves the consistency and accuracy of relief representation and supports analyses of human–environment interactions, with applications in land-use planning, environmental management, agriculture, mineral exploration, and protected-area management.

**ARTICLE HISTORY**
Received 27 June 2025
Revised 14 October 2025
Accepted 15 January 2026

**KEYWORDS**
Geomorphometric mapping; basic landform unit; geomorphology

## 1. Introduction

A map is one of the oldest cultural expressions that has been developed in parallel with the advance of civilization since its earliest manifestations (Gomes, 2004; Harley, 2009). Even before the invention of writing, primitive people were able to create maps and charts for orientation. Developments in navigation and discoveries in the 15th and 16th centuries catalyzed continuous progress in Cartography until the first half of the twentieth century. This field has advanced significantly, driven by technological innovations that began replacing manual operations with mechanical processes and subsequently using electronic equipment. In the last two decades, conventional mapping methods have been progressively replaced by digital formats, which offer a more dynamic and interactive representation of the Earth's surface (Robison et al., 1995).

Geomorphological mapping has been essential in understanding the processes that have shaped the Earth's surface, providing valuable information for various disciplines such as Geology, Geography, Hydrology, and Ecology, and serving as the basic tool for graphic and spatial representations of objects and phenomena (Florenzano, 2008; Goudie et al., 2022). Maps, accompanied by informative legends, make the results of geomorphological analyses and interpretations concrete. Despite the introduction of geographic information systems (GIS) and advances in digital mapping techniques, which enable layered visualization and three-dimensional representation of the Earth's surface (Quesada-Román & Peralta-Reyes, 2022; Smith & Clark, 2005), the complexity of geomorphological maps often presents challenges for non-specialist users (Smith et al., 2011). This difficulty is exacerbated by the diversity and complexity of the objects of study in Geomorphology, which demands a standardization of representation that has not been widely established yet (Florenzano, 2008).

The lack of standardization in geomorphological cartographic representation hinders the understanding of its historical development and conceptual bases to enable the identification of methodological standards that can favor a more precise quantification of relief. In this context, Geomorphometry, i.e. the science of measuring the shapes of the Earth's surface (Sofia, 2020; Xiong et al., 2022) has emerged as an effective strategy for representing the structural organization of relief since it allows detailed analysis and categorization of geomorphological features using numerical parameters. The interpretation of relief and its dynamics has strengthened the relationship

CONTACT Gervásio Barbosa Soares Neto gervasio.neto@ifb.edu.br Instituto Federal de Brasília, Av. Cedro, AE 15, QS 16 – Riacho Fundo I, Brasília – DF CEP 71.826-006, Brazil
Supplemental data for this article can be accessed online at https://doi.org/10.1080/17445647.2026.2626113.

between geomorphological mapping and physiographic representation of geological units in detriment of the morphological description of relief (Soares Neto & Martins, 2019). Advances in the acquisition and processing of aerial and orbital remote sensing data have helped in various geological and geomorphological studies of different regions and at different scales. The precise and focused delimitation of the object of study has enabled geology to employ this new technology to refine and standardize its representation processes. On the other hand, Geomorphology has become fixated on remote sensing tools, abandoning its main object of study, which is the description of landforms.

The importance of defining landforms in geomorphological mappings was emphasized by Evans (2012). This definition, which is often neglected, is essential for effective relief representation. The lack of representation standards and the classification of the Earth's modelling reflect the need for a clearer approximation of relief units, based on specific morphometric characteristics. The development of routines based on digital elevation models (DEM) and the application of geomorphometric parameters offer a promising way to refine geomorphological mapping, allowing for a more accurate and objective representation of the relief (Bishop et al., 2012; Sampaio & Augustin, 2014). Using the basic relief unit (BRU) proposed by Soares Neto and Martins (2019) as a starting point, the classification of geomorphological features is based on geomorphometric patterns such as amplitude and slope, unlike classic methods that consider genetically homogeneous surfaces. In this approach, the representation of the relief is based on morphometric similarities, providing a clearer and more practical delimitation of BRU, as shown by Yang et al. (2025) who used the BRU concept to produce a global map of BRUs with a resolution of 1 arc second (approximately 30 meters). The application of geomorphometry not only proposes advances in the method of representation but also makes a significant contribution to understanding the interactions between relief features and practical applications in environmental management and territorial planning.

Currently, the most detailed geomorphological map of Brazil is the one produced by the Brazilian Institute of Geography and Statistics (IBGE) at a scale of 1:250,000 (IBGE, 2025). However, this map is somewhat limited for detailed studies and specific analyses, for example on a micro-basin scale, as pointed out by Rocha et al. (2022). In 2019, during the 1st Workshop on the Brazilian System of Relief Classification, objectives for the construction of the SBCR were defined. According to IBGE (2020), these objectives include: organizing and hierarchizing a multiscale taxonomy of the national relief; and providing a reference for future mappings, enabling correlation and continuity in space and time. Factors such as defining a relief classification method that is replicable, comparable, and continuous in space and time, as well as establishing the cartographic scale level to be adopted, are fundamental for creating a reference system for relief classification. The method adopted in the discussion for classifying the Brazilian relief is based on taxons (levels). Despite the advances achieved, the construction of the proposal in progress is very similar to the method used to consolidate the geomorphological map by IBGE (2009) thus far. According to Botelho and Pelech (2019), the scientific community itself points out that the relief classification method defined by IBGE (2009) is considered complex and difficult to understand. Our proposal focuses on defining the relief based on ruptures in the compartments (e.g. plateaus and depressions), taking into account fundamental differences in elevation, slope and available relief (Soares Neto & Martins, 2019).

In addition, new proposals for geomorphological mapping based on semi-automated procedures are emerging with the aim of reducing subjectivity during the mapping process itself (Jasiewicz & Stepinski, 2013; Silveira et al., 2018; Trentin et al., 2015). Thus, the aim of this work is to represent the geomorphological cartography of Brazil with an emphasis on geomorphometric data, using the concept of BRU to offer a more rigorous and faithful representation of landforms. The map produced by the authors has the advantage of being more detailed than the IBGE geomorphological map at a scale of 1:250,000. Within this context, we hope that research involving, for example, determining areas with high potential for environmental degradation and areas with high potential for agricultural intensification involving environmentally sustainable practices, will be produced with greater accuracy and reliability. The objective of this paper is therefore to represent the geomorphological cartography of Brazil with an emphasis on geomorphometric data, using the concept of BRU to provide a more accurate and faithful representation of landforms.

## 2. Theoretical and methodological basis

The theoretical and methodological approach of this work was based on the method proposed by Soares Neto and Martins (2019) and the methodological roadmap defined as 'relief physiology'. This physiology is centered on the delimitation of watersheds, which are key units in Physical Geography (Christofoletti, 1980; Sanjaume & Villanueva, 1996). The method uses the delimitations of seven river basins proposed by the National Water Agency (ANA) (Figure 1). The higher the value of the system, the greater the level of detail of the cartographic scale, increasing the detail of the relief. Based on the concepts of Horton (1945) and Strahler (1952), it can be said that the geomorphometric analysis of the relief becomes robust when the

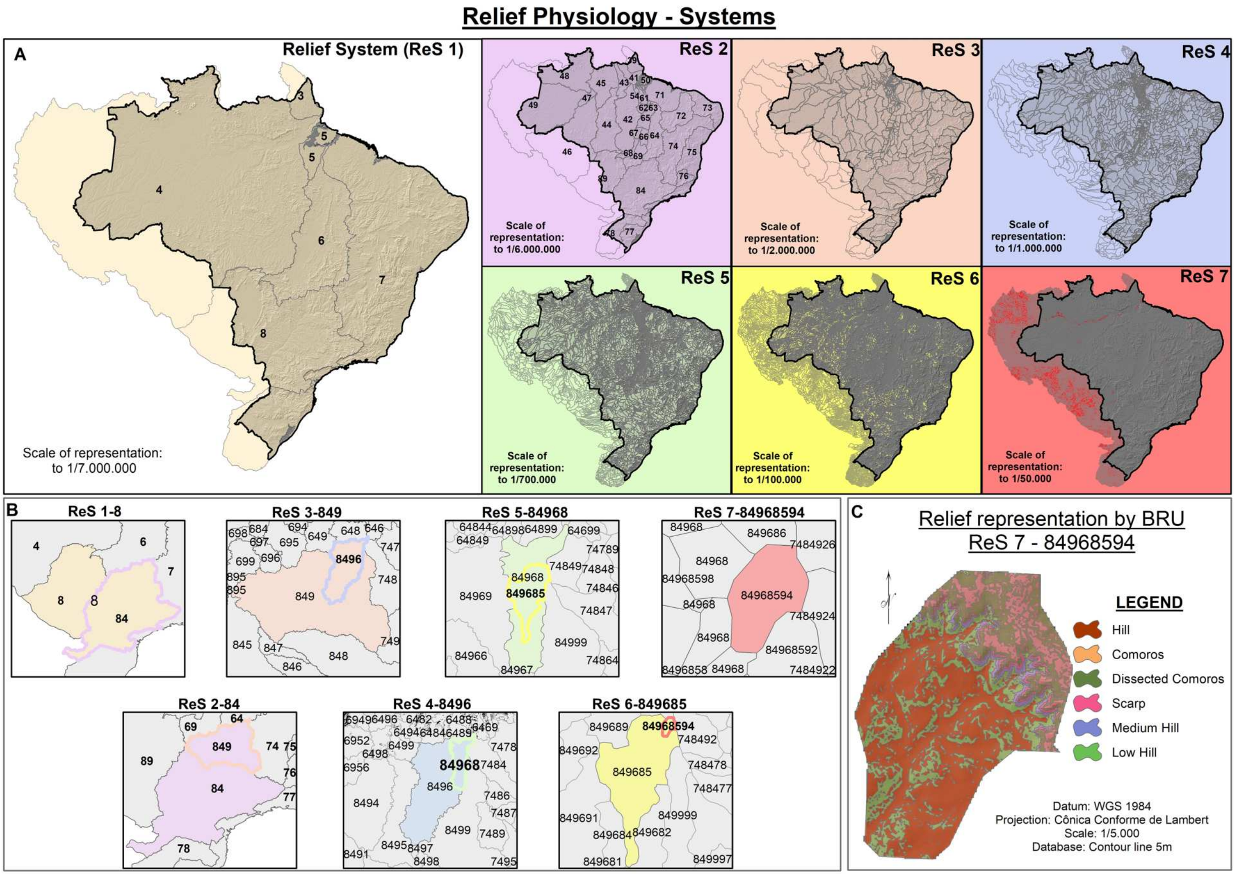


**Figure 1.** Representation of the division of the seven relief systems and the corresponding codes for each hydrographic region and their cartographic representation scales (A). In (B), an example of the representation of each relief system and its respective coding. In (C), the geomorphology of a hydrographic region in relief system 7, identified by the code 84968594.

analytical quantification is derived from parameters such as the dimensions of basins, sub-basins or micro-basins, which determine the dimensions and metric patterns of the relief. The highest level of the system represents the highest level of cartographic representation of the relief that will be related to the input database, i.e. the EAW used as a reference.

The understanding of BRU as fundamental unit for classifying geomorphological features is based on the geomorphometric patterns of available relief and slope. This gives an initial perception of 'height' and 'slope', allowing the cognitive and empirical translation of the relief (Soares Neto & Martins, 2019). The delimitation of BRU in each relief system is based on topographic correlation, defining regions by topographic archetypes concentrated on distinct altimetric gradients. The determination of the topographic correlation is based on the lowest value of the altimetric range (h), divided by the relief range of the analyzed river basin (H), and on the area of each relief band divided by the total area of the basin. This approach determines the limits of the available relief range. The use of the hypsometric inflection defines the inflection points of the polynomial line of the curve resulting from the topographic correlation, elucidating the available relief ranges. The inflection points and local maxima of the curve establish patterns in the topographic behavior of an area. The mathematical modelling includes a polynomial of degree n (with $R^2 \geq 0.9$), from the topographic correlation determines the amplitude of the available relief, which is represented by Equation 1: $p(x) = a_n x^n + a_{n-1} x^{n-1} a_{n-2} x^{n-2} + \ldots. + a_0 = \sum_{k=0}^{n} a_k x^k$, $x = \frac{h}{H}$ and $R^2 \geq 0.9$ point of local maximum is $\bar{x}$ so that:

$$\frac{dp}{dx}(\bar{x}) = 0$$
$$\leftrightarrow n a_n \bar{x}^{n-1} + (n-1) a_{n-1} \bar{x}^{n-2} + \ldots + 1 a_1$$
$$= 0 \leftrightarrow \sum_{k=1}^{n} (k) a_k \bar{x}^{k-1} = 0$$

& point of inflexion is $\bar{x}$ so that:

$$\frac{d^2 p}{dx^2}(\bar{x}) = 0$$
$$\leftrightarrow n(n-1) a_n \bar{x}^{n-2} + (n-1)(n-2) a_{n-1} \bar{x}^{n-3}$$
$$+ \ldots + 2.1 a_2$$
$$= 0 \leftrightarrow \sum_{k=2}^{n} (k)(k-1) a_k \bar{x}^{k-2} = 0 \quad (1)$$

The second layer of analysis, focused on slope, is determined through the clinographic inflection points

(Cif) and clinographic maximum (Cmax), analyzing the polynomial line of the frequency curve. This results in slope distribution patterns, revealing the roughness of the terrain and flatter or steeper zones, offering a detailed analysis of surfaces. The ranges obtained by the inflection points and local maxima denote patterns of slope distribution of a given area. These clinographic archetypes show levels of roughness in the terrain, delimiting flatter and steeper surfaces. Therefore, the rule for delimiting slope bands can be understood as the local points of inflection and maximum of the regression line, a polynomial of degree n (with $R^2 \geq 0.9$), of the slope frequency curve, represented by Equation (2):

$$p(x) = a_n x^n + a_{n-1} x^{n-1} a_{n-2} x^{n-2} + \ldots + a_0 = \sum_{k=0}^{n} a_k x^k$$

, $x = \frac{h}{H}$ and $R^2 \geq 0, 9$ point of local maximum is $\bar{x}$ so that:

$$\frac{dp}{dx}(\bar{x}) = 0 \leftrightarrow n a_n \bar{x}^{n-1} + (n-1) a_{n-1} \bar{x}^{n-2} + \ldots + 1 a_1 = 0 \leftrightarrow \sum_{k=1}^{n} (k) a_k \bar{x}^{k-1} = 0$$

& point of inflexion is $\bar{x}$ so that:

$$\frac{d^2 p}{dx^2}(\bar{x}) = 0 \leftrightarrow n(n-1) a_n \bar{x}^{n-2} + (n-1)(n-2) a_{n-1} \bar{x}^{n-3} + \ldots + 2.1 a_2 = 0 \leftrightarrow \sum_{k=2}^{n} (k)(k-1) a_k \bar{x}^{k-2} = 0 \quad (2)$$

The BRU are thus delimited considering the map algebra between the intervals of available relief and slope and, if necessary, the insertion of other geomorphological parameters such as slope orientation, landforms, morphostructure and morphochronology, among others (Figure 2).

## 3. Results and discussion

The BRU were defined by integrating the slope and available relief intervals for each basin that composes the relief system 1 (ReS1). This procedure was replicated for all six ReS1 component basins, facilitating the definition of specific BRU singularities, categorized by frequency of relief forms (Figure 3).

Fifteen BRU were identified based on the combination of available relief and slope data, associated with relief forms. The map generated, with a more detailed scale compared to previous geomorphological representations of Brazil (IBGE, 2025), provides a more precise level of geomorphometric information. This plays a crucial role in environmental studies, such as erosion susceptibility and natural resource management, taking advantage of remote sensing data to improve activities such as mineral exploration and water management (Carabella et al., 2019; Ferreira et al., 2017; Keller et al., 2020; Rao, 1978; Remondo et al., 2008; Schneider et al., 2020).

By defining the boundaries of the BRU and other geomorphometric parameters (slope forms), it was possible to determine the singularities of the different BRUs. The frequencies of the slope forms were defined by analyzing the histogram class by class (Figure 4).

Fifteen BRUs were obtained from the combination of available available relief and slope (Figure 5). For greater discretion, each BRU was associated with the predominance of slope forms, so each class had the following characteristics:

**Plain –** relief up to 80 meters and slopes up to 6%, with a predominantly straight-planar slope form, represents 3.53% of the Brazilian territory.

**Fluvial Terrace –** relief varying between 40 and 260 meters and slopes up to 6%, predominantly straight-planar slope form, represents 8.18% of the Brazilian territory.

**Alluvial Fan Low –** relief up to 40 meters and slope up to 4%, predominantly straight-planar slope forms, represents 0.75% of the Brazilian territory.

**Alluvial Fan Medium –** relief varying between 41 and 80 meters and slopes up to 4%, predominantly straight-planar slope form, represents 0.72% of the Brazilian territory.

**Alluvial Fan High –** relief up to 80 meters and slope up to 2%, predominantly straight-planar slope forms, represents 0.20% of the Brazilian territory.

**Depression –** relief varying between 61 and 420 meters, 441 and 480 meters, and 681–800 meters and slopes up to 6%, predominantly straight-planar slope form, represents 8.71% of the Brazilian territory.

**Dissected Depression –** relief varying between 61 and 680 meters and slope up to 15%, predominantly convergent-planar slope form, represents 10.70% of the Brazilian territory.

**Scarp –** relief up to 2980 meters and slope greater than 14%, with a predominant convergent-divergent slope form, represents 1.01% of the Brazilian territory.

**Dissected Plateau –** relief varying between 301 and 2980 meters and slopes between 4% and 14%, predominantly convex-planar slope form, represents 4.05% of the Brazilian territory.

**Demoted Tableland –** relief varying between 401 and 800 meters and slopes up to 14%, predominantly convergent-planar slope form, represents 14.05% of the Brazilian territory.

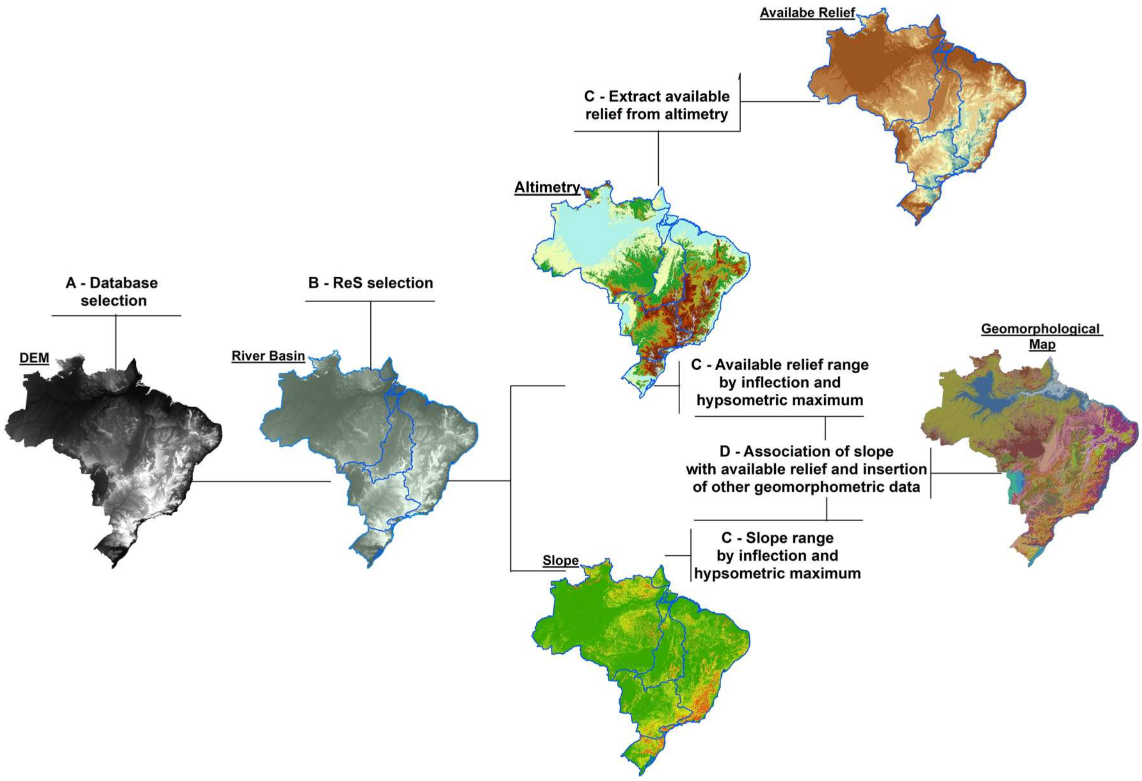


**Figure 2.** Stages for obtaining the basic relief units and defining the geomorphological representation. The first stage (A) corresponds to choosing the DEM that will define the level of detail of the representation. The second stage (B) refers to defining which relief system covers the area to be represented. The third stage (C) defines the basic relief units based on the correlation of available relief and slope intervals. The last stage (D) refers to defining the relief classes and their respective names and characteristics.

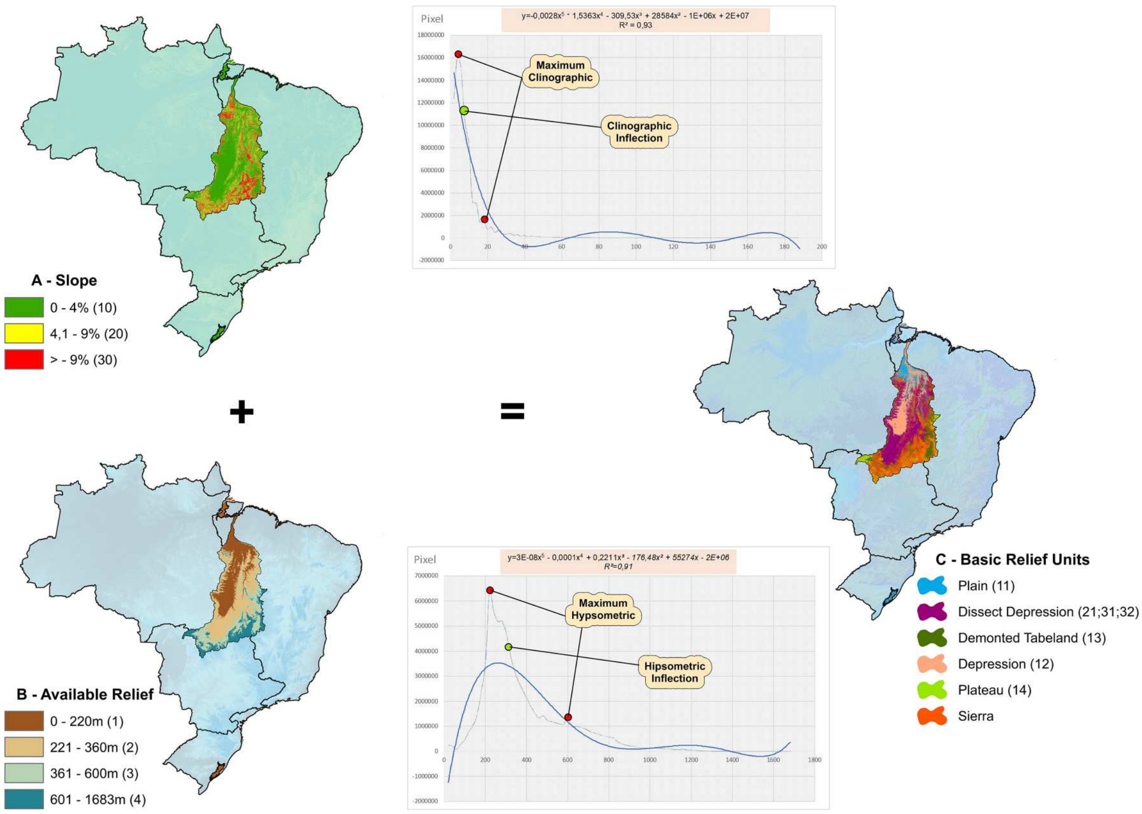


**Figure 3.** Correlations between slope (A) and available relief (B) to determine the basic relief unit classes (C) and graphs used to obtain the available relief and slope intervals for one of the six relief systems (ReS) that composes the Brazilian territory. $R^2$ values greater than 0.9.

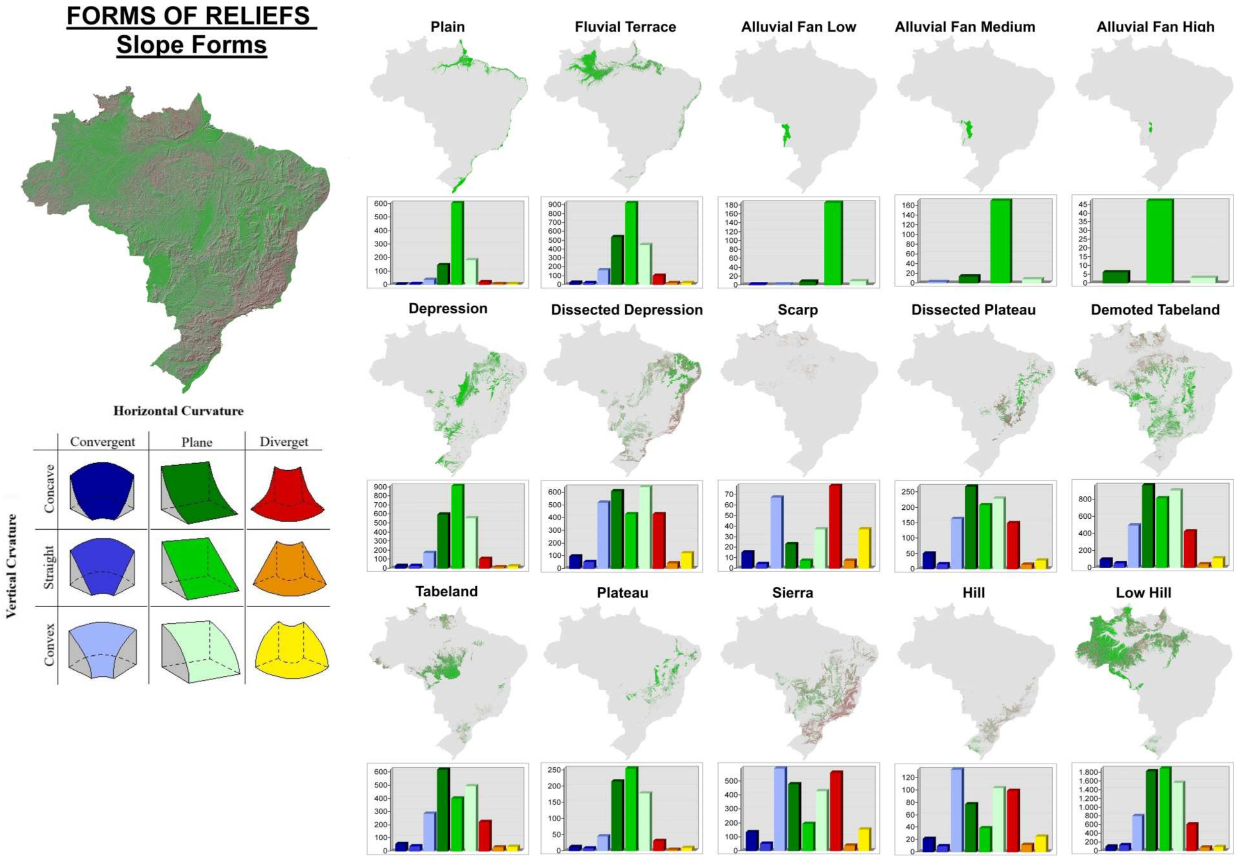


**Figure 4.** Histograms of slope forms determining the frequency of each basic relief unit (BRU) class.

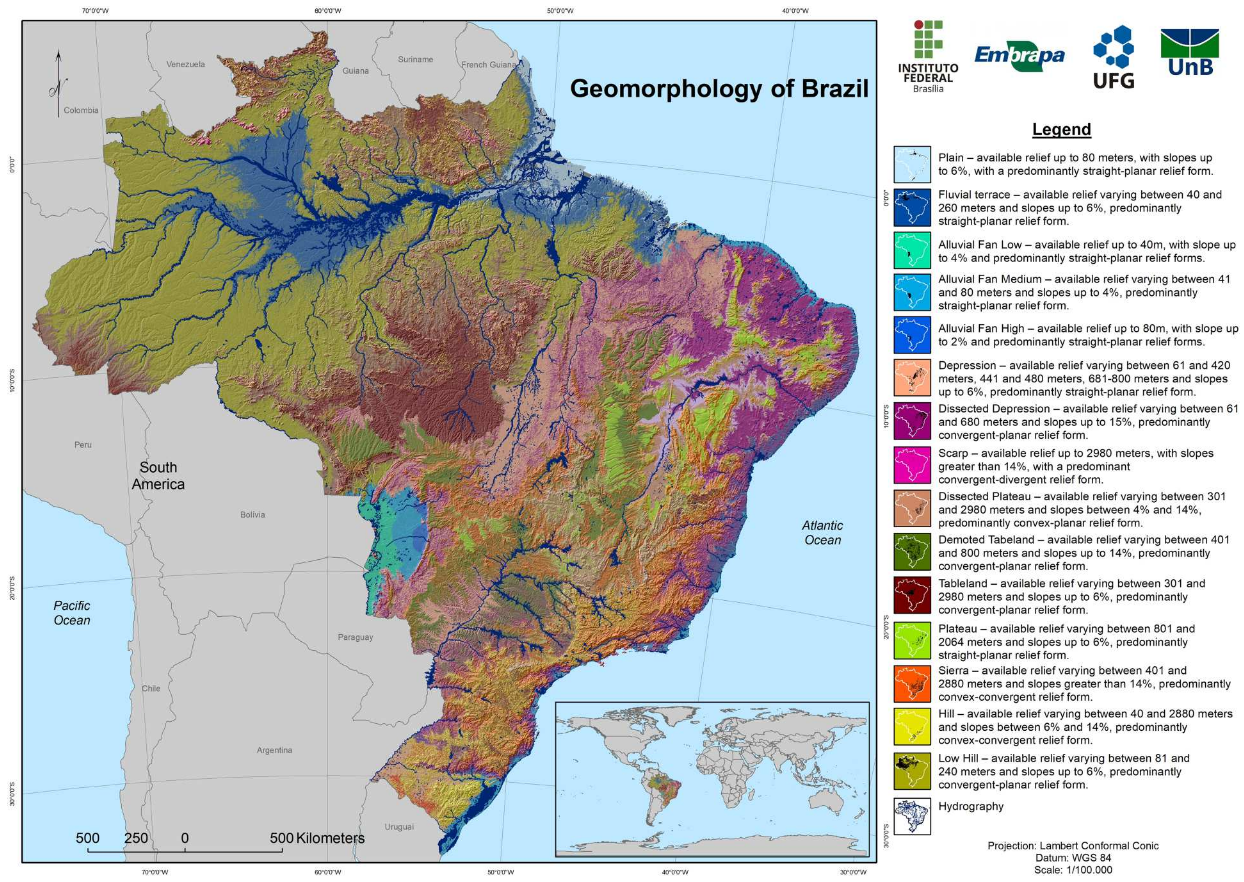


**Figure 5.** Geomorphological map of Brazil.

**Tableland –** relief varying between 301 and 2980 meters and slopes up to 6%, predominantly convergent-planar slope form, represents 8.09% of the Brazilian territory.

**Plateau –** relief varying between 801 and 2064 meters and slopes up to 6%, predominantly straight-planar slope form, represents 2.78% of the Brazilian territory.

**Sierra –** relief varying between 401 and 2880 meters and slopes greater than 14%, predominantly convex-convergent slope form, represents 9.58% of the Brazilian territory.

**Hill –** relief varying between 40 and 2880 meters and slopes between 6% and 14%, predominantly convex-convergent slope form, represents 1.96% of the Brazilian territory.

**Low Hill –** relief varying between 81 and 240 meters and slopes up to 6%, predominantly convergent-planar slope form, represents 25.71% of the Brazilian territory.

## 4. Conclusions

Geomorphological mapping of Brazil based on geomorphometric parameters provides a more faithful representation of landscape, using mathematical models to delineate main geomorphometric archetypes and identify relief metric classes that reflect actual terrain conditions. This approach not only offers more accurate insights into geomorphology but also contributes significantly to environmental planning and management. It provides valuable support in drawing up conservation and sustainable development policies by offering detailed data on soil susceptibility to erosion, geological hazards, and hydrological resources. In addition, the use of geomorphometric parameters makes it possible to identify and categorize different types of relief more precisely, facilitating the application of mitigation and conservation measures in vulnerable areas.

Implementing this methodology not only improves the accuracy of geomorphological representations but also promotes a deeper understanding of the complex interactions between geomorphological factors and human activities. This is particularly relevant in the management of protected areas, urban planning, agriculture, and mineral exploration, where detailed information about relief can direct strategic land use and occupation decisions.

In short, geomorphological representation through geomorphometric parameters represents a significant advance in modern cartography, acting as an essential tool for scientists, planners and managers, highlighting the importance of integrating new technologies and methodological approaches to face contemporary environmental challenges.

## Software

The main map was prepared using ArcMap 10.4 software. The calculations to define the regression curve, the inflection points and the maximum of the regression curve used WolframAlfa (online).

## Open Scholarship

This article has earned the Center for Open Science badge for Open Data. The data are openly accessible at https://plataforma.brasil.mapbiomas.org/ .

## Acknowledgments

I thank and dedicate this work to Professor Maria Amélia Leite S. Nascimento and Professor Valter Casseti for all their care and contributions to Brazilian Geomorphology.

## Disclosure statement

No potential conflicts of interest were reported by the authors.

## Data availability statement

The data supporting the information presented in this workare available from the corresponding author, upon reason-able request.

## ORCID

*Gervásio Barbosa Soares Neto* http://orcid.org/0000-0002-5036-8757
*Edson Eyji Sano* http://orcid.org/0000-0001-5760-556X
*Vinicius Vasconcelos* http://orcid.org/0000-0002-2396-8597
*Karla Maria Silva Faria* http://orcid.org/0000-0001-9381-932X
*Eder De Souza Martins* http://orcid.org/0000-0003-2881-683X

## References

Bishop, M. P., James, L. A., ShroderJr.J. F., & Walsh, S. J. (2012). Geospatial technologies and digital geomorphological mapping: Concepts, issues and research. *Geomorphology*, *137*, 5–26. https://doi.org/10.1016/j.geomorph.2011.06.027

Botelho, R. G. M., & Pelech, A. S. ( 2019). From IBGE Geomorphological Mapping to a Brazilian System of Relief Classification. *Revista Brasileira de Geografia, Rio de Janeiro*, *64*(1), 183–201.

Carabella, C., Miccadei, E., Paglia, G., & Sciarra, N. (2019). Post-wildfire landslide hazard assessment: The case of the 2017 Montagna Del Morrone fire (Central Apennines, Italy). *Geosciences*, *9*, 175. https://doi.org/10.3390/geosciences9040175

Christofoletti, A. (1980). *Geomorfologia*. Edgard Blücher.

Evans, I. S. (2012). Geomorphometry and landform mapping: What is a landform? *Geomorphology*, *137*, 94–106. https://doi.org/10.1016/j.geomorph.2010.09.029

Ferreira, M. E., Ferreira, L. G., Latrubesse, E. M., & Miziara, F. (2017). The Forests of the Amazon and Cerrado Moderate Regional Climate and Are the Key to the Future. *Tropical Conservation Science*, *10*, 33–47. https://doi.org/10.1177/1940082917720671

Florenzano, T. G. (2008). *Geomorfologia: Conceitos e Tecnologias Atuais*. Oficina de Texto.

Gomes, M. C. A. (2004). Velhos mapas, novas leituras: Revisitando a História da Cartografia. *GEOUSP: Espaço e Tempo (Online)*, *16*, 67–79. https://doi.org/10.11606/issn.2179-0892.geousp.2004.73955

Goudie, A. S., Burt, T. P., & Viles, H. A. (2022). The global transformation of geomorphology. *Geological Society, London, Memoirs*, *58*, 1–17. https://doi.org/10.1144/M58-2021-37

Harley, B. (2009). Mapas, saber e poder. *Confins*, *5*, 2–4.

Horton, R. E. (1945). Erosional development of streams and their drainage basins: Hydrophysical approach to quantitative morphology. *Bulletin of the Geological Society of America*, *56*, 275–370.

IBGE. (2009). *Manual Técnico de Geomorfologia*. Coordenação de Recursos Naturais e Estudos Ambientais. 2nd ed. Rio de Janeiro. 182 p.

IBGE. (2020*). 1st Workshop on the Brazilian System of Relief Classification*. IBGE Technical Report. Rio de Janeiro, 1–77. 2020.

IBGE. (2025). *Geomorfologia 1:250.000*. Retrieved February 02, 2025, from https://www.ibge.gov.br/geociencias/informacoes-ambientais/geomorfologia/10870-geomorfologia.html

Jasiewicz, J., & Stepinski, T. F. (2013). Geomorphons — a pattern recognition approach to classification and mapping of landforms. *Geomorphology*, *182*, 147–156. https://doi.org/10.1016/j.geomorph.2012.11.005

Keller, K., Adamaitis, C., Alessio, P., Anderson, S., Goto, E., Gray, S., Gurrola, L., & Morell, K. (2020). Applications in geomorphology. *Geomorphology*, *366*, 106729. https://doi.org/10.1016/j.geomorph.2019.04.001

Quesada-Román, A., & Peralta-Reyes, M. (2023). Geomorphology mapping global trends and applications. *Geographies*, *3*, 610–621. https://doi.org/10.3390/geographies3030032

Rao, D. P. (1978). Utility of Landsat coverage in small scale geomorphological mapping-some examples from India. *Journal of the Indian Society of Remote Sensing*, *6*, 49–56.

Remondo, J., Bonachea, J., & Cendrero, A. (2008). Quantitative landslide risk assessment and mapping on the basis of recent occurrences. *Geomorphology*, *94*, 496–507. https://doi.org/10.1016/j.geomorph.2006.10.041v

Robison, A. H., Morrison, J. L., Muehrcke, P. C., Kimerling, A. J., & Guptill, S. C. (1995). *Elements of Cartography* (6th ed). John Wiley & Sons.

Rocha, A. B. A., Barbosa, V. R. F., Faria, K. M. S., Martins, E. S., & Soares Neto, G. B. (2022). Geomorphologic map of the Brazilian Cerrado by geomorphometric archetypes. *Revista Brasileira de Geomorfologia*, *23*, 1674–1684. https://doi.org/10.20502/rbg.v23i3.2132

Sampaio, T. V. M., & Augustin, C. H. R. R. (2014). Índice de concentração da rugosidade: Uma nova proposta metodológica para o mapeamento e quantificação da dissecação do relevo como subsídio a cartografia geomorfológica. *Revista Brasileira de Geomorfologia*, *15*, 47–60. https://doi.org/10.20502/rbg.v15i1.376

Sanjaume, M. S., & Villanueva, R. J. B. (1996). *Teoría y Método en Geografía Física*. Editorial Sintesis.

Schneider, A., Bonhage, A., Raab, A., Hirsch, F., & Raab, T. (2020). Large-scale mapping of anthropogenic relief features—legacies of past forest use in two historical charcoal production areas in Germany. *Geoarchaeology*, *35*, 545–561. https://doi.org/10.1002/gea.21782

Silveira, C. T., Silveira, R. M. P., Trentin, R., & Robaina, L. E. S. (2018). Classificação automatizada de elementos de relevo no estado do Paraná (Brasil) por meio da aplicação da proposta dos geomorphons. *Revista Brasileira de Geomorfologia*, *19*, 33–57. https://doi.org/10.20502/rbg.v19i1.1263

Smith, M. J., & Clark, C. D. (2005). Methods for the visualization of digital elevation models for landform mapping. *Earth Surface Processes and Landforms*, *30*, 885–900. https://doi.org/10.1002/esp.1210

Smith, M. J., Paron, P. & Griffiths, J. S. (2011). *Geomorphological mapping: methods and applications* (1st ed.). Amsterdam: Elservier.

Soares Neto, G. B., & Martins, E. S. (2019). Método semiautomático de delimitação das unidades básicas de relevo. *Revista Brasileira de Geomorfologia*, *20*, 397–409. https://doi.org/10.20502/rbg.v20i2.1403

Sofia, G. (2020). Combining geomorphometry, feature extraction techniques and Earth-surface processes research: The way forward. *Geomorphology*, *355*, 107055. https://doi.org/10.1016/j.geomorph.2020.107055

Strahler, A. N. (1952). Hypsometric (area-altitude) analysis of erosional topography. *Bulletin of the Geological Society of America*, *63*, 1117–1142.

Trentin, R., Robaina, L. E. S., & Silveira, C. T. (2015). Compartimentação geomorfométrica da bacia hidrográfica do rio Itú/RS. *Revista Brasileira de Geomorfologia*, *16*, 219–237.

Xiong, L., Li, S., Tang, G., & Strobl, J. (2022). Geomorphometry and terrain analysis: Data, methods, platforms and applications. *Earth-Science Reviews*, *233*, 104191. https://doi.org/10.1016/j.earscirev.2022.104191

Yang, X., Li, S., Ma, J., Chen, Y., Zhou, X., Li, F., Xiong, L., Zhou, C., Tang, G., & Meadows, M. (2025). Global basic landform units derived from multi-source digital elevation models at 1 arc-second resolution. *Earth Systems Science Data*, *17*, 4331–4350. https://doi.org/10.5194/essd-17-4331-2025