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GEOMORPHOLOGICAL COMPARTMENTALIZATION APPLIED TO LAND USE AND OCCUPATION IN THE MUNICIPALITY OF CAMPO FORMOSO (BA)

COMPARTIMENTAÇÃO GEOMORGOLÓGICA APLICADA AO USO E OCUPAÇÃO DA TERRA DO MUNICÍPIO DE CAMPO FORMOSO (BA)

COMPARTIMENTACIÓN GEOMORFOLÓGICA APLICADA AL USO Y OCUPACIÓN DEL SUELO EN EL MUNICIPIO DE CAMPO FORMOSO (BA)

Matheus de Alencar ALMEIDA[1]
e-mail: matheus.alencar@discente.univasf.edu.br

Sirius OLIVEIRA SOUZA[2]
e-mail: sirius.souza@univasf.edu.br

Kelly Beatriz Silva SANTOS[3]
e-mail: kelly.beatriz@discente.univasf.edu.br

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[1] Federal University of the São Francisco Valley (UNIVASF), Senhor do Bonfim – Bahia – Brazil. Undergraduate student in the Geography Teaching Degree Program.
[2] Federal University of the São Francisco Valley (UNIVASF), Senhor do Bonfim – Bahia – Brazil. Associate Professor, Geography Department.
[3] Federal University of the São Francisco Valley (UNIVASF), Senhor do Bonfim – Bahia – Brazil. Undergraduate student in the Geography Teaching Degree Program.

ABSTRACT: Given the scarcity of research in tropical semi-arid environments, this article performs the geomorphological compartmentalization of the municipality of Campo Formoso (BA, Brazil), following the National Policy for Civil Defense and Protection (Law 12.608/2012) guidelines. The methodology was structured in four stages: (I) bibliographic review; (II) digital stereoscopy for aerial imagery analysis; (III) georeferencing, vectorization, and data integration in QGIS 3.30.0; and (IV) final writing. Results identified units such as the Campo Formosense Pediplano, Northern and Residual Plateaus, Terraces, and Alluvial Plains. Moreover, the presence of wind farms in the region highlights the relevance of geomorphological studies for territorial planning, supporting urban management and environmental preservation. Such studies contribute to risk mitigation and promote sustainable development in Bahia state's semi-arid region.

KEYWORDS: Geomorphological mapping. Territorial Planning. Geoprocessing. Planning. Semi-arid.

RESUMO*: Diante da escassez de estudos detalhados em ambientes semiáridos tropicais, este trabalho realiza a compartimentação geomorfológica do município de Campo Formoso (BA), alinhando-se às diretrizes da Política Nacional de Proteção e Defesa Civil (Lei 12.608/2012). A metodologia foi dividida em quatro etapas: (I) revisão bibliográfica; (II) estereoscopia digital para análise de imagens aéreas; (III) georreferenciamento, vetorização e integração de dados no QGIS 3.30.0; e (IV) redação final. Os resultados revelaram unidades como o Pediplano Campo Formosense, Planaltos Setentrionais e Residuais, Terraços e Planícies Aluviais. Além disso, a presença de parques eólicos na região destaca a relevância de estudos geomorfológicos aplicados ao ordenamento territorial, contribuindo para o planejamento urbano e a preservação ambiental, com vistas à mitigação de riscos e à promoção do desenvolvimento sustentável no semiárido baiano.*

PALAVRAS-CHAVE*: Mapeamento geomorfológico. Ordenamento territorial. Geoprocessamento. Planejamento. Semiárido.*

RESUMEN*: Ante la escasez de estudios en ambientes semiáridos tropicales, este trabajo realiza la compartimentación geomorfológica del municipio de Campo Formoso (BA, Brasil), siguiendo los lineamientos de la Política Nacional de Defensa y Protección Civil (Ley 12.608/2012). La metodología se estructuró en cuatro etapas: (I) revisión bibliográfica; (II) estereoscopía digital aplicada al análisis de imágenes aéreas; (III) georreferenciación, vectorización e integración de datos en QGIS 3.30.0; y (IV) redacción final. Los resultados identificaron unidades como el Pediplano de Campo Formoso, las Mesetas Norte y Residual, las Terrazas y las Llanuras Aluviales. Asimismo, la instalación de parques eólicos en la región evidencia la importancia de los estudios geomorfológicos aplicados a la planificación territorial, aportando a la gestión urbana y la preservación ambiental, orientadas a mitigar riesgos y fomentar el desarrollo sostenible en el semiárido del estado da Bahía.*

PALABRAS CLAVE*: Mapeo geomorfológico. Ordenación del territorio. Geoprocesamiento. Planificación. Semiárido.*

Introduction

Natural environments undergo changes over time, which are accelerated by anthropogenic interventions, leading to a series of instabilities in landscape dynamics that result in social and natural impacts (Ross, 2006).

These environmental imbalances are evident in many municipalities of the semi-arid region of Bahia, where issues related to relief are observed, such as soil erosion, degradation of water resources, and desertification. Moreover, the semi-arid region of Bahia has been affected by the inadequate implementation of new forms of land use and occupation (Souza; Lima, 2025).

Considering land use and occupation as distinct ways in which human societies utilize and appropriate space (Brazilian Institute of Geography and Statistics [IBGE], 2013), practices such as deforestation, the discharge of effluents into watercourses, and landfilling highlight a lack of concern for territorial planning and management. These practices frequently disregard the environmental vulnerability of such areas, resulting in irreversible damage to ecosystems.

In this context, the study of Geomorphology is fundamental to understanding environmental vulnerability and the physical processes of terrain (Ross, 1990). This relationship is intrinsic to the discipline itself, as Christofoletti (1980) establishes that Geomorphology is the science that studies landforms and the processes acting upon morphological landscapes.

According to Tricart (1965), geomorphological science identifies elements such as structure, chronology, and dynamics, enabling the delineation of natural phenomena as well as the effects of anthropogenic interventions on natural environments. For this delineation to be effective, the wide range of elements involved in geomorphological studies is emphasized, particularly geomorphological cartography, which is structured through components such as morphology, morphometry, morphodynamics, morphostructure, and morphochronology (Marques Neto, 2020).

Furthermore, geomorphological cartography is a necessary tool for planning, as it allows not only the identification of problems arising from inappropriate land use, but also the prevention of natural phenomena and events caused by anthropogenic intervention, in addition to enabling the control, assessment, and monitoring of environmental threats (Saadi, 1997).

In the international context, Wang *et al*. (2008) identified, in the semi-arid regions of China and southern Mongolia, the presence of alluvial fans adjacent to the Gobi Desert and highlighted the need for planning in these environments. Likewise, Lei *et al*. (2020) studied areas susceptible to erosion in the Robat Turk watershed, a semi-arid region of Iran, using geomorphological cartography, which led to proposals for environmental preservation through mapping of susceptible areas.

In the national context, Falcão Sobrinho, Gomes, and Vital (2023) characterized a sub-watershed of the Jaibaras River in the state of Ceará by mapping taxonomic levels of relief and soil erosion vulnerability, identifying erosive processes in linear forms such as gullies and technogenic terrains. Additionally, Lima et al. (2023) analyzed an experimental watershed in the municipality of Floresta, Pernambuco, characterized by extensive eroded areas, and identified severe levels of susceptibility to desertification. Furthermore, Reis and Souza (2023) examined the importance of geomorphological mapping as a basis for land use and occupation planning in the municipality of Antônio Gonçalves, Bahia, considering areas with potential susceptibility to erosive processes.

Given the above, the main objective of this study is to propose a geomorphological compartmentalization for the municipality of Campo Formoso (BA), with the aim of contributing to land use and occupation planning. Accordingly, this study is initially justified by its social relevance, in light of the instruments of the National Policy for Protection and Civil Defense (PNPDEC), established by Federal Law No. 12,608 (Brasil, 2012a), which reflects among its fundamental principles actions related to prevention and the mapping of mountainous areas, as well as the subsequent integration of sectoral policies such as territorial planning, urban development, and environmental management.

Theoretical Framework

Landform shape is understood as the result of the interaction between geological and geomorphological processes acting at different temporal scales, ranging from the geological scale to the historical scale, in which anthropogenic action may generate technogenic landforms (Ross, 2006). It is precisely from the articulation of these elements that the fundamental taxonomic models for Brazilian geomorphological cartography were developed, conceived with the purpose of overcoming the evolutionary conceptions of William Morris Davis, as expressed in the proposal of the Geographical Cycle (Davis, 2013; Simon; Lupinacci, 2019).

Historically, discussions on landform mapping have been guided by the multiscale complexity of forms and processes associated with surface modeling, making the geomorphological map a tool of high scientific relevance due to the diversity of data it encompasses (Silveira; Silveira, 2021).

Since the mid-twentieth century, there has been a consensus that the geomorphological map should integrate morphometry, which refers to spatial properties such as dimension, slope, and curvature; morphography, the objective description of forms; morphogenesis, which addresses origin and evolution in relation to genetic agents and processes; morphodynamics, which examines the occurrence of current processes; and morphochronology, which discusses the relative or absolute age of landforms (IBGE, 2009; Silveira; Silveira, 2021).

In Brazil, a country of continental dimensions and vast geoenvironmental complexity, the evolution of this cartographic practice has followed the demands for territorial knowledge, planning, and resource management, reflecting different schools of thought over time.

Initially, studies of Brazilian relief were strongly influenced by the French school, focusing on large regional compartmentalizations. However, it was with Aziz Ab'Sáber that geomorphological analysis acquired a national identity. His works—although not strictly focused on detailed mapping methodologies—established the foundations of the morphoclimatic compartmentalization of the territory (Ab'Sáber, 2003). Thus, the identification of major morphoclimatic domains represented a synthesis effort that systematically correlated, for the first time, relief, climate, soil, and vegetation, providing the basis for all subsequent regional mappings.

The need for more systematic and applied mapping intensified during the 1960s and 1970s, in line with governmental planning demands. The influence of Jean Tricart (1965), with his proposal for integrated mapping through the components of morphography, morphogenesis, morphodynamics, and surface formations, was fundamental during this period. This complex and detailed approach was adopted and adapted in several projects, notably in the RADAMBRASIL Project, which represented the largest integrated mapping effort of the national territory. This project resulted in an extensive collection of data on the physical environment, in which geomorphological mapping played a key role in understanding natural resources and land use and occupation potentialities (Brasil, 1983).

The consolidation of a methodological proposal for geomorphological mapping adapted to the specificities of the Brazilian territory was achieved through the work of Jurandyr Ross. In view of the symbolic complexity of European systems, such as that proposed by Tricart (1965), and the need for a standard capable of integrating different scales of analysis—from the continental to the local scale—Ross (1992) proposed a hierarchical taxonomic classification system. The core of this approach lies in the compartmentalization of relief into taxonomic levels that reflect the decreasing influence of genetic factors.

The first taxon, morphostructure, is defined by large-scale tectonic compartmentalization, such as sedimentary basins. The second taxon, morphosculpture, distinguishes units resulting from erosional or depositional morphostructures, reflecting the action of morphoclimatic processes on the structural base, such as plateaus and plains. From these, lower-level taxa are defined—namely, landforms—which detail local morphography and morphodynamics (Ross, 1992).

In this context, this systematization provided an integrative and reproducible logic, enabling geomorphological mapping in Brazil to overcome the dichotomy between regional analyses, often descriptive in nature, and detailed surveys. As a result, it has become a fundamental reference for environmental analysis and territorial planning in the country.

Currently, geomorphological mapping in Brazil is experiencing a technological phase. The conceptual foundations established—particularly by Jurandyr Ross—are now integrated with Geographic Information Systems (GIS). In the current context, the availability of Digital Elevation Models (DEMs) also allows for the automated and semi-automated extraction of relief parameters, such as slope, aspect, and curvature, which support the delimitation of geomorphological units.

Accordingly, contemporary authors have focused on adapting classical proposals to these new digital tools, aiming at greater precision and applicability in environmental risk modeling, erosion studies, and urban planning (Guerra; Cunha, 2001; Florenzano, 2008). Contemporary mapping employs geomorphometry to segment and objectify terrain analysis, while theoretical knowledge is applied to interpret these patterns. Thus, the ultimate objective is to understand both morphogenesis—that is, the origin and historical evolution of landforms—and morphodynamics, namely the processes such as erosion, sedimentation, and mass movements that currently act upon these forms. Therefore, geomorphological mapping is constantly evolving, consolidating itself not only as a diagnosis of the past and present, but also as a dynamic and indispensable analytical tool for effective territorial planning and risk management.

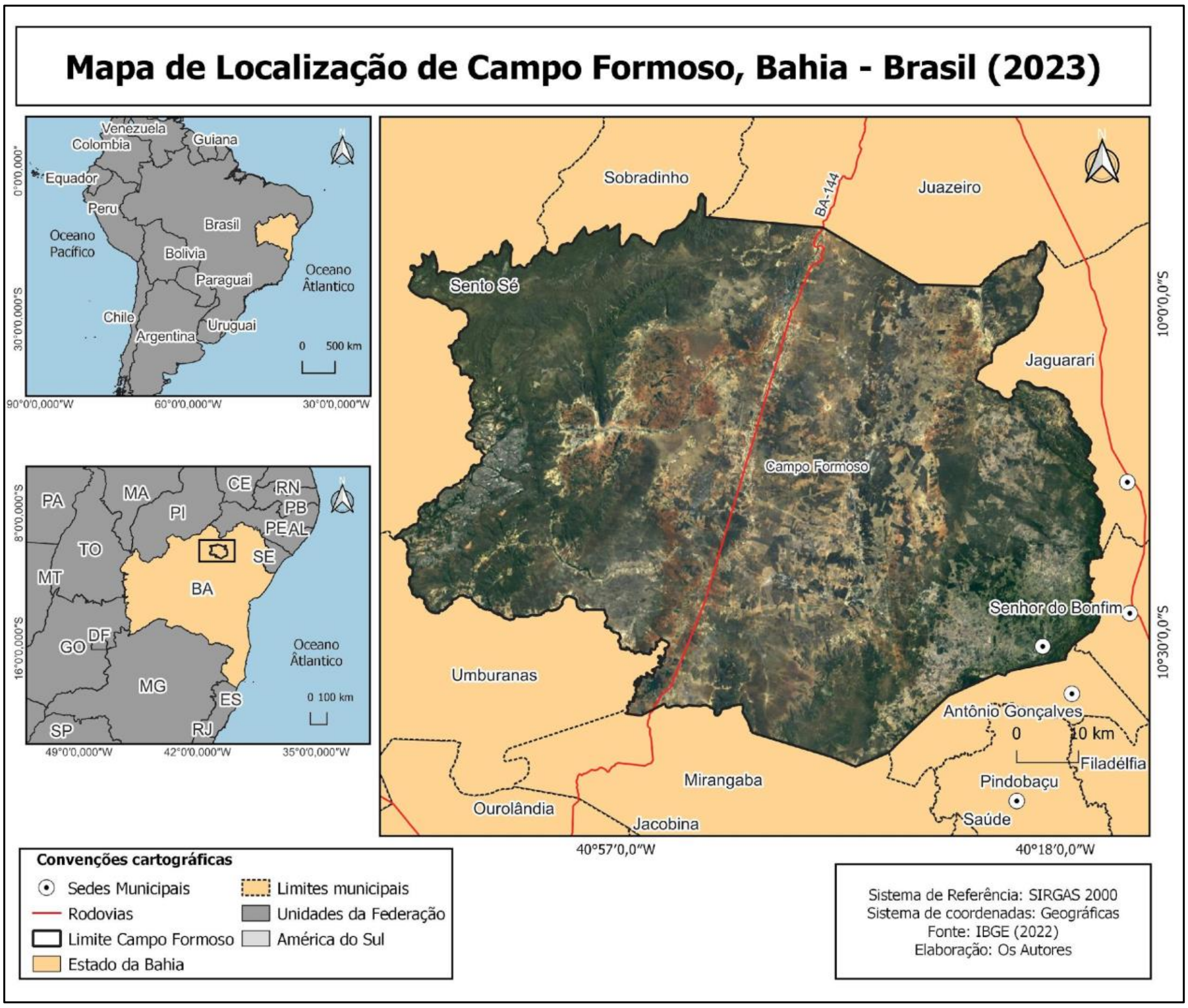
Methodology

Characterization of the Study Area

In the semi-arid region of Bahia, the municipality of Campo Formoso, Bahia, was selected as the study area. It is located between the parallels 10°16′29″S and 10°33′12″S and the meridians 40°17′22″W and 40°46′01″W of Greenwich, and is part of the Piemonte Norte do Itapicuru Identity Territory. The municipality covers an area of approximately 7,438.07 km² (IBGE, 2022).

Situated in the Centro-Norte Mesoregion of Bahia (Figure 1), Campo Formoso is bordered to the north by the municipalities of Juazeiro and Sobradinho; to the east by Senhor do Bonfim and Jaguarari; to the west by Sento Sé and Umburanas; and to the south by Antônio Gonçalves and Mirangaba (SEI, 2015).

Figure 1 – Location map of the municipality of Campo Formoso (BA)



Source: Prepared by the authors (2023).

Due to its geographic location, the study area is characterized by a semi-arid climate (BSh), with average annual rainfall between 700 and 900 mm and an average annual temperature of 24°C. Additionally, the municipality of Campo Formoso presents a climatic context marked by the occurrence of dry periods, as well as lower temperatures in winter and probable rainfall during the summer (Brasil, 1983).

With regard to geological characteristics, the municipality of Campo Formoso reveals a subsurface of remarkable mineral wealth, standing out as the largest chromite reserve in the Americas and one of the world's leading emerald mining hubs, in addition to hosting limestone and marble deposits. The region is structured by granitic rocks dating from the Paleoproterozoic Era (CPRM, 2005), associated with the Saúde Complex and the Juacema Suite (Brasil, 1983).

Concerning geological units, the municipality lies within the domain of the São Francisco Supergroup, originating in the Lower Proterozoic, which comprises an extensive sequence of mafic–ultramafic rocks exceeding 900 m in thickness (Brazil, 1983). Within this geological context, the Tombador, Caboclo, and Morro do Chapéu formations stand out, as well as the Gabriel Unit, Nova América Unit, Detrital–Lateritic Cover, and the Carnaíba–Itamotinga Complex (IBGE, 2025).

Regarding soil types, the following classes were identified within the territory: Argisols, Cambisols, Latosols, Neosols, and Planosols (Brazil, 1983; CPRM, 2005). Argisols correspond to soil groups characterized by clay accumulation processes and occur more frequently in the extreme western sector adjacent to the residual plateaus of the Serra da Jacobina (IBGE, 2025).

Cambisols are more widely distributed, particularly within the Campo Formosense Pediplain in the central portion of the municipality, and are characterized by well-drained soils with variable depths, ranging from shallow to deep. Neosols comprise the youngest soils in the municipal territory and correspond to isolated areas in both the western strip and the eastern strip along the limits of the northern plateaus. Latosols, in turn, are prominent in areas farther from the central territory, especially in the extreme southern zones, while Planosols occupy a small western portion of the study area; these soils are associated with rocky outcrops of the Serra da Jacobina (Brasil, 1983).

With respect to hydrographic characteristics, the municipality of Campo Formoso is intersected by two hydrographic basins: the Salitre River Basin (SRB) and the Itapicuru River Basin (IRB). Approximately 70% of Campo Formoso's territorial area lies within the SRB, whose total extent covers 38,664 km². Around 30% of the municipality is part of the IRB, which has a total area of 14,136 km² (INEMA, 2013).

In terms of vegetation, there is a predominance of Caatinga vegetation; however, altimetric variation contributes to the formation of ecotonal areas, characterized by higher humidity levels and the presence of rupestrian forest (CPRM, 2005). Thus, in the southern and southeastern portions of the Serra da Jacobina, dense arboreal Caatinga predominates. Conversely, in the central-western strip of the Caatinga zone, medium- and low-stature vegetation is observed, composed mainly of cacti, xerophytic species, and bromeliads. Additionally, in the central-eastern portion of the municipal territory, vegetation cover is characterized by large trees forming forests and woodlands associated with more humid environments (IBGE, 2025).

From a demographic perspective, the municipality of Campo Formoso has a population of 71,377 inhabitants and a population density of 9.97 inhabitants/km². The municipal territory currently presents a GDP per capita of 18,422.89 and stands out for its extractive mining activities, as well as for the agricultural and livestock sector (IBGE, 2022).

Methodological Procedures

This study was structured into three stages: the first was based on a bibliographic review of geomorphological cartography in tropical semi-arid environments; the second consisted of the acquisition of aerial images and the execution of digital stereoscopy; the third stage involved georeferencing, vectorization, and data integration within a Geographic Information System (GIS) environment using QGIS software (version 3.30.0); and the final stage comprised the writing of the final manuscript. Accordingly, the main procedures related to the second, third, and fourth stages of the research are detailed below.

Initially, digital aerial photographs at a scale of 1:70,000 were obtained, made freely available by the Bahia Mineral Research Company (CBPM) (2005). Following image acquisition, stereoscopic pairs were interpreted using StereoPhoto Maker software, version 5.06. The interpretation followed the Anaglyph method, which results in the superimposition of stereoscopic photographs in complementary colors—blue and red—allowing depth perception when viewed with appropriate colored-lens glasses. The three-dimensional images generated from the stereoscopic pairs were saved in .tiff format for subsequent use within the GIS environment (Souza; Oliveira, 2012).

Vectorization was thus characterized by the collection and delimitation of the main geomorphological features and compartments of the area, identified based on sampling keys (Figure 2) and patterns observed in digital anaglyph images. This creation process, carried out using the commands “create new layer” and “add features,” enabled the specific mapping of the following compartments: Campo Formosense Pediplain, Northern Plateaus, Residual Plateaus of the Serra da Jacobina, Inselbergs, and Alluvial Terraces and Plains.

As a complement, contour lines, hillshade derived from TOPODATA, and satellite images at a scale of 1:5,000 were used through the command QuickMapServices > Google Satellite to support the identification of the study area. Given the low quality of the aerial photographs, hillshade derived from the Digital Elevation Model (TOPODATA) was used as a complementary dataset for the preliminary identification and delimitation of potential areas via the command raster > analysis > hillshade (INPE, 2008). In this regard, TOPODATA provides a detailed set of terrain elevation data with a 30 m resolution and offers resources that enhance data accuracy and quality, delivering efficient data collection methods and customized solutions based on detailed geospatial information (INPE, 2008).

Subsequently, nine random samples were extracted from the dissection modeling in order to quantitatively measure the degree of fluvial work on the topography. Two main metrics were adopted: horizontal dissection and vertical dissection. The former, referring to the average distance between interfluves or drainage divides, was determined using the “Line” tool, accessed through the command sequence Processing > Toolbox > Line, in accordance with the methodological procedures established by IBGE (2009). The second metric—vertical dissection—assessed the altimetric amplitude of the dissected relief, based on the guidelines of the RADAMBRASIL Project (Brasil, 1983), Ross (1992), and the methodological contributions of Lima and Lupinacci (2021). The results of the dissection calculation are presented in Table 1 below.’1

Table 1 – Dissection Index of the Municipality of Campo Formoso (BA)

VERTICAL DISSECTION	DISSECAÇÃO HORIZONTAL				
	Very Small	**Small**	**Medium**	**Large**	**Very Large**
	< 500	500 |- 1.000	1.000 |- 1.500	1.500 |- 2.000	>2.000
Very weak(≤ 450)	5.1	4.1	3.1	2.1	1.1
Weak (450|-900)	5.2	4.2	3.2	2.2	1.2
Moderate (900|-1.350)	5.3	4.3	3.3	2.3	1.3
Strong (1.350|-1.800)	5.4	4.4	3.4	2.4	1.4
Very Strong (≥ 1.800)	5.5	4.5	3.5	2.5	1.5

Source: Adapted by the authors (2023).

Therefore, it is emphasized that visual interpretation of the study area is fundamental for the development of geomorphological mapping. In addition, for this study, interpretation keys were developed based on the criteria of the IBGE Geomorphological Manual (2009), through which a taxonomic system was established, as presented in Table 2, along with the interpretative key of relief shown in Figure 2.

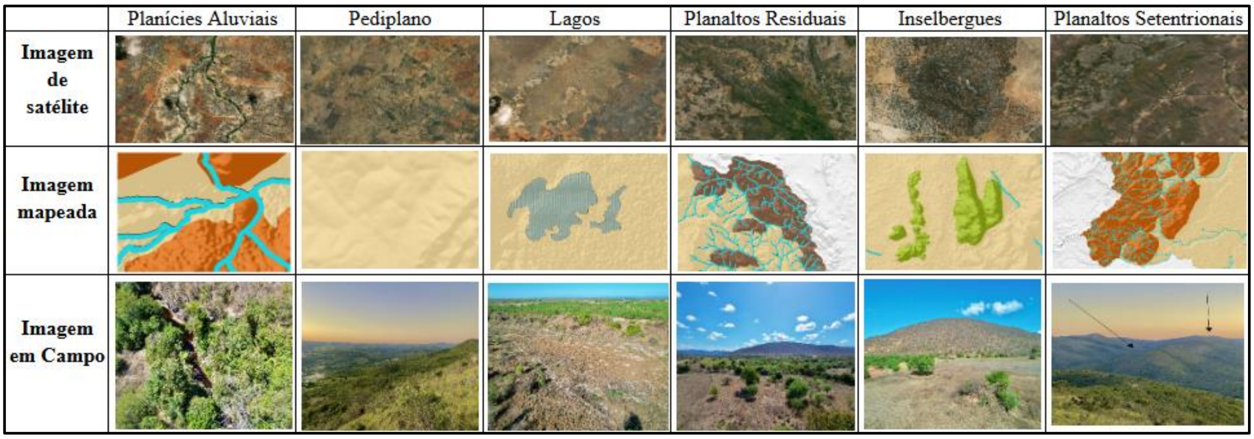
Table 2 – Geomorphological Classes Adapted from IBGE

Taxonomic Level	Definition	Examples of Representation in the Study Area
Domínio Morfoestrutural	Occur at a regional scale and organize geomorphological features according to the geological framework, marked by rock nature and active tectonics.	The Campo Formoso area lies within the São Francisco Craton Domain, structured by the Saúde Complex and the Juacema Suite.
Geomorphological Regions	Comprised of compartments inserted within the underlying morphostructural framework, defined by structural rock factors that confer common genetic characteristics and group similar features related to surface formation and vegetation physiology under past and present climatic influences.	The study area is located within the Southern Sertaneja Depression, the Diamantina Plateau, and the Northern Bahia Residual Ranges (IBGE, 2009).
Geomorphological Units	A variety of altimetric levels and physiognomically similar forms in different modeling styles.	Lowlands of the Jacaré and Salitre Rivers, Northern Plateau Blocks of the Chapada Diamantina, Serra da Jacobina, Morro do Chapéu Plateaus, plains, fluvial terraces, the Serra da Jacobina, and a small portion of continental water bodies within the territory.

Landform Models	Modeled polygons consist of relief patterns that share similar geometric definitions, common origins, and active morphogenetic processes, resulting in recurring correlated surface materials.	The geomorphological models present in the study area are divided into accumulation, planation, dissection, and dissolution.
Forms	Features that can only be represented by linear or point symbols due to their size.	The forms identified in the municipality include karst, pediplain, and plain.

Source: Adapted from IBGE (2009).

Figure 2 – Sample Classes of Landform Features in the Municipality of Campo Formoso (BA)



Source: Photographs and drone images prepared by the authors (2023); satellite images provided by Bing Virtual Earth (Microsoft, 2023).

After completing the geomorphological compartmentalization, fieldwork was carried out with the purpose of validating the information obtained and verifying the previously identified results. Subsequently, the predominant landforms within the municipal territory were identified, and the delimitation of sampling points was established.

Additionally, the description of the sampling points was based on the guidelines of the field form from the Geomorphology Technical Manual (IBGE, 2009). GPS was used as an auxiliary tool for measuring altitude and recording the sampling locations. Furthermore, images captured by a DJI AIR 2S drone were employed to identify geomorphological features within the study area.

Results and Discussion

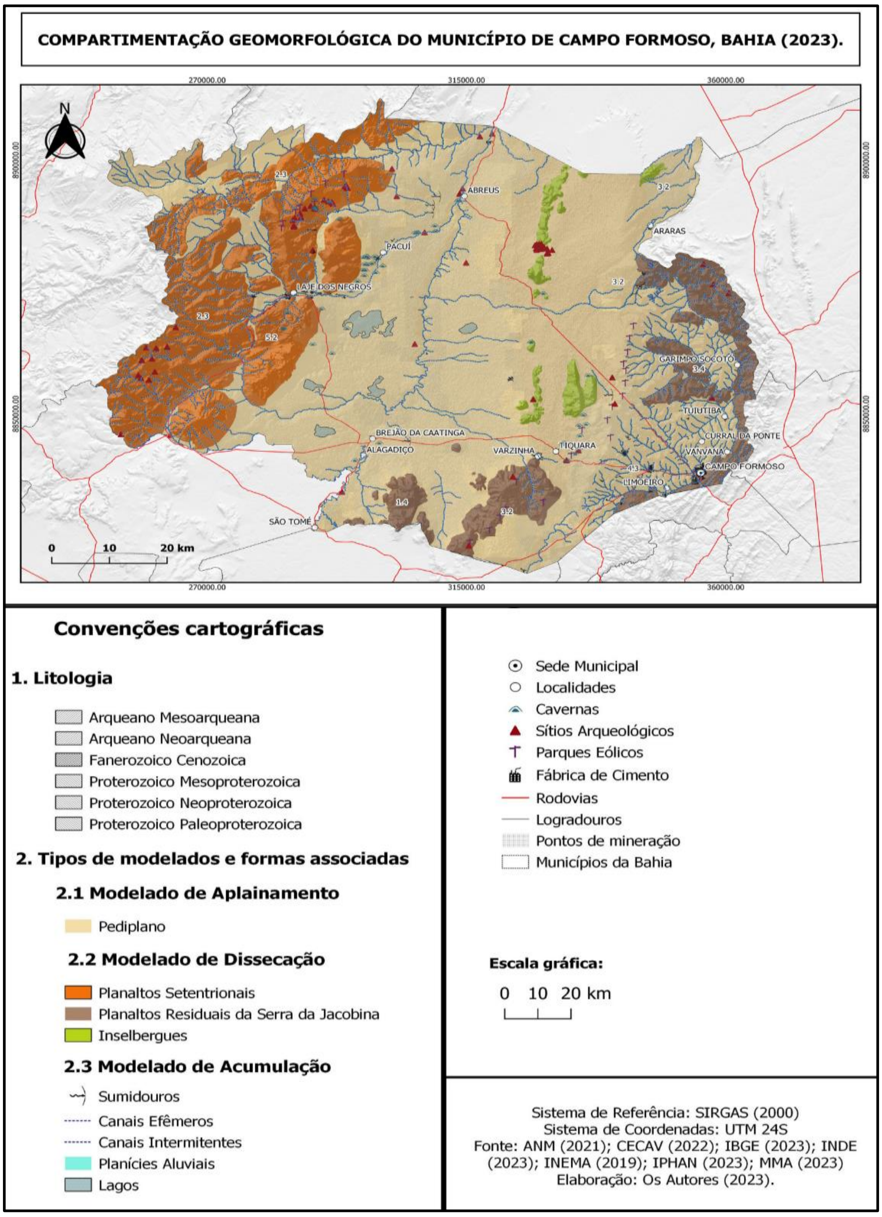
According to Table 3, the geomorphological compartment map of the study area (Figure 3) indicates the predominance of the planation model represented by the Campo Formoso Pediplain.

Table 3 – Geomorphological Compartments in the Municipality of Campo Formoso (BA)

Models	Compartments	Area (Km²)	Area (%)
Planation	Campo Formoso Pediplain	4.437,35	61,96
Dissection	Northern Plateaus	1.378,94	19,25
	Residual Plateaus of Serra da Jacobina	576,36	8,05
	Inselbergs	122,38	1,71
Accumulation	Alluvial Terraces and Plains	646,8	9,03
Total		7.161,82	100,00

Source: Authors' elaboration (2023).

Figure 3 – Geomorphological Compartmentalization of the Municipality of Campo Formoso (BA)



Source: Authors' elaboration (2023).

Regarding the planation model, the Campo Formoso Pediplain dominates the study area, covering 4,437.35 km², corresponding to 61.96% of the municipality. This unit is classified as a gently inclined, planated surface, composed of forms capped by discontinuous detrital material over bedrock (Bigarella; Meis; Silva, 2016).

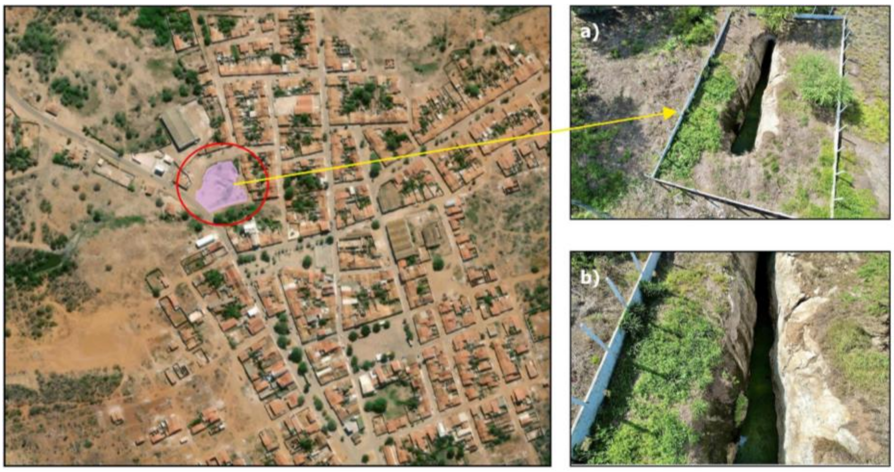
The Campo Formoso Pediplain is characterized as the result of erosive processes occurring at the base of steeper slopes, featuring a thick alluvial layer that develops where it meets the alluvial plains of the valleys (Jatobá, 1994; Passos; Bigarella, 1998; Reis; Souza, 2022).

Within Campo Formoso, the mapped pediplain exhibits a high occupation rate, predominated by relief compartments and including the municipal seat and localities such as the villages of Tiquara, Lage dos Negros, and Brejão da Caatinga (IBGE, 2022).

The Campo Formoso Pediplain holds significant land use and occupation. Although this feature is favorable and legally permitted for occupation, it is also susceptible to periodic flooding and waterlogging. Therefore, monitoring by municipal authorities is necessary (Brasil, 2012a; Reis; Souza, 2023).

Additionally, a doline was identified in the field in the village of Tiquara, located 25 km from the municipal seat, as shown in Figure 4.

Figure 4 – Location Map of the Doline in the Village of Tiquara



Source: Authors' elaboration (2023).

In this context, it is relevant to highlight that dolines are oval-shaped depressions with smooth, non-angular contours, featuring steep slopes and rock outcrops (Christofoletti, 1980), without connection to surface drainage networks (IBGE, 2009).

The presence of a doline indicates karstic relief (Ferreira; Uagoda, 2020), which typically occurs in areas of carbonate rocks—namely, thickly bedded, folded, and fractured soluble limestones and dolomites (IBGE, 2025). It is important to emphasize that such formations may trigger both social and environmental impacts, as they are generally unsuitable for occupation. Awareness of site preservation is essential, along with the regulated development of adjacent activities, such as mineral extraction, which require careful planning, monitoring, and regulation.

Additionally, pedestal formations adjacent to the Northern Plateaus were observed in the study area (Figure 5). These features form when runoff removes exposed soil but leaves columns protected by resistant materials like small rocks or vegetation root mats, highlighting the vulnerability of the exposed soil.

Figure 5 – Pedestal Formation in the Study Area

Source: Authors' elaboration (2023).

It is important to note that pedestals are elevated and isolated soil or rock features that develop gradually due to susceptibility to erosion; such formations may indicate the process of desertification (Rios, Carvalho, & Oliveira, 2020).

Regarding dissection modeling, the Northern Plateaus stand out as the main geomorphological feature in the eastern portion of the municipal territory, as shown in Figure 7. This unit covers 19.25% of the municipality, equivalent to 1,378.94 km².

In the eastern strip of the municipality, the dissection index ranges from 5.2 to 2.3, as indicated in Table 1. This area exhibits a low level of vertical dissection combined with moderate to strong horizontal dissection. Areas where the index reaches 5.2 are notable, with vertical dissection below 400 meters, indicating a terrain with limited incision (Table 1).

Within this same sector lies the quilombola community of Lage dos Negros (Figure 7), situated between two Northern Plateaus. This geomorphological setting intensifies erosive processes, posing potential risks of slope failures and mass movements (Reis; Souza, 2023).

In this context, it is crucial to emphasize the Land Subdivision Law (Brazil, 1979), which mandates continuous evaluations by public managers of such occupation areas to ensure orderly development, preservation of vulnerable zones, and protection of human life (Brasil, 1981).

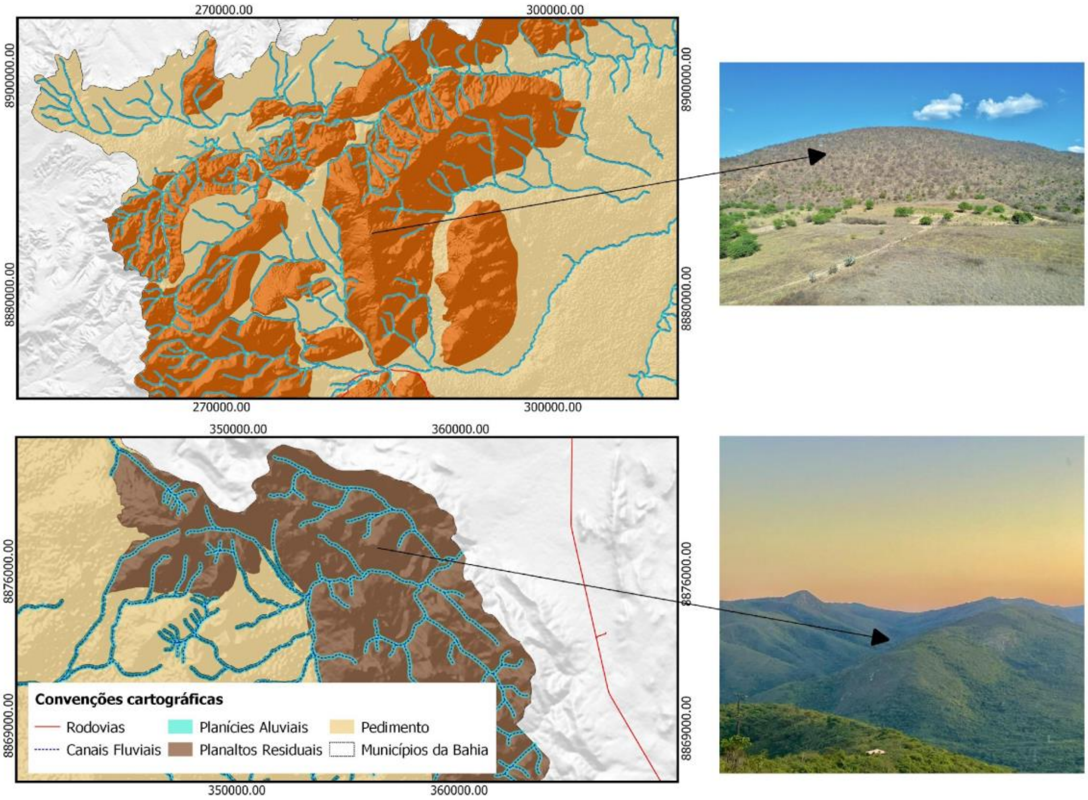
Concerning the diagnosis of the Residual Plateaus of the Serra da Jacobina, this compartment occupies 8.05% of the study area, equivalent to 576.36 km² in the western municipality. The Serra da Jacobina is characterized as a complex mountain system, lithologically composed of quartzites, phyllites, metaconglomerates, migmatites, gneisses, micaceous schists, calcsilicate rocks, and mafic and ultramafic rocks consistent with granite intrusions (Brasil, 1983).

The dissection index in this area ranges from 4.3 to 3.4, with zones of moderate to strong vertical dissection and low to moderate horizontal dissection. For the 3.4 range, vertical dissection values vary between 1,350 m and 1,800 m (Table 1).

Within this context, the localities of Garimpo Socotó, Vanvana, and Limoeiro present significant occupation rates near the Residual Plateaus of Serra da Jacobina. These areas exhibit strong dissection indices with vertical dissection values below 500 meters, as shown in Table 1.

Regarding land use and occupation in these sites, geotechnical monitoring conducted by experts in geotechnical and civil engineering is recommended (Brazil, 1979; Brazil, 1983; Ross, 2006) to prevent potential disasters and protect both society and the natural environment. Additionally, such monitoring is essential for preserving elevated areas, such as hilltops and mountain ranges (Brazil, 2012a). Figure 6 illustrates the distribution of plateau compartments in the eastern and western bands of the study area.

Figure 6 – Distribution of Dissection Modeling of Plateaus in Campo Formoso (2023)



Source: Authors (2023). Note: a) Northern Plateaus; b) Residual Plateaus of Serra da Jacobina.

The inselbergs identified in the study area are located in the northern and western zones of the municipality and are isolated features (Jatobá, 1994). Inselbergs cover 1.71% of the municipality's area, equivalent to 122.38 km².

Furthermore, it is important to highlight the presence of wind farms established both in the eastern and western regions of Campo Formoso, located near traditional communities. For example, the Ventos do Sertão Wind Farm, part of the Morrinhos Wind Complex, is situated in the rural area adjacent to traditional communities such as Fazenda Quina and Borda da Mata, which belong to the Fundo de Pasto social group, as shown in Figure 7 (Dantas; Sampaio; Souza, 2022).

According to the Bahia Wind Atlas, Campo Formoso has high wind energy potential. The Ventos do Sertão Wind Farm lies in the rural zone of the study area, near the aforementioned traditional communities (Dantas; Sampaio; Souza, 2022).

Figure 7 – Occurrence of the Wind Farm in the Communities of Fazenda Quina and Borda da Mata

Source: Author's private collection (2023).

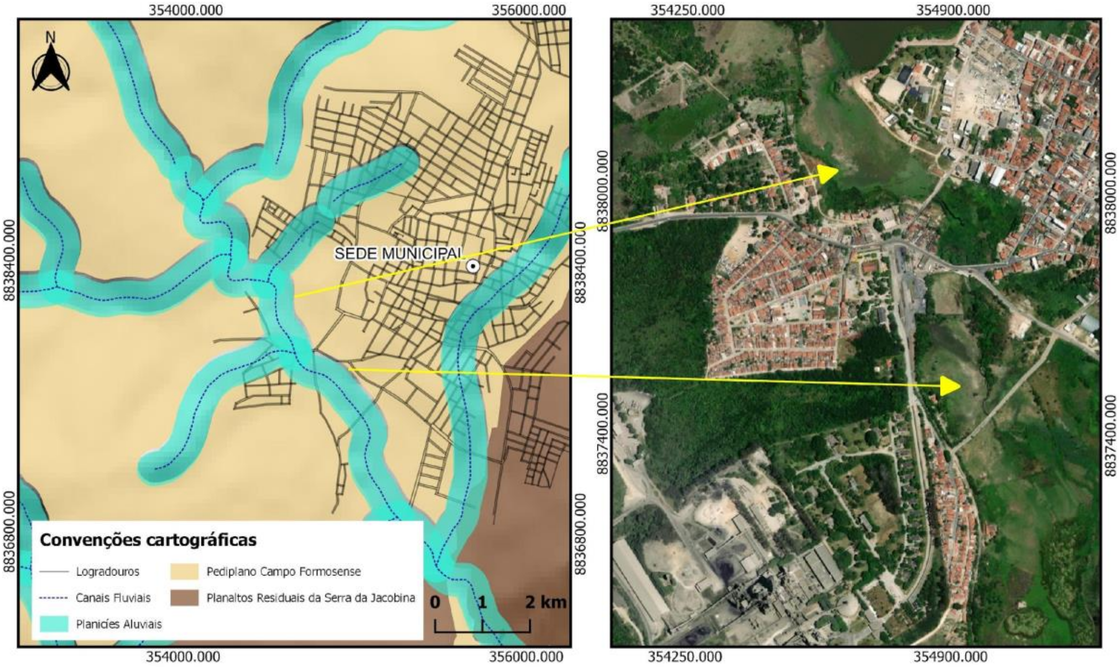
Regarding the occupation of this area, it is reiterated that this type of land use results in environmental impacts, requiring the implementation of environmental management instruments to mitigate these effects (Brasil, 1981).

In turn, the accumulation model, represented by the Alluvial Plains and Terraces unit, covers 646.8 km², equivalent to 9.03% of the study area. This unit results from fluvial accumulation and is subject to periodic flooding (IBGE, 2009).

In Campo Formoso, the alluvial plains are associated with intermittent and ephemeral watercourses. These features result from the overflow of river waters during flood periods and river inundation (Ab'Saber, 1975). Examples of intermittent rivers in the region include the Salitre and Itapicuru Rivers, which carry water seasonally and dry up at other times.

Concerning planning in these areas, it is notable that both the municipal seat of Campo Formoso and surrounding localities lie within these plains and exhibit high occupation rates (Figure 8). It is therefore critical to emphasize the preservation of these features and restrict occupation, as the fluvial channels are subject to dynamic processes that render them unstable, with potential for flooding and periodic inundation.

Figure 8 – Occurrence of the Accumulation Model in the Western Strip of Campo Formoso



Source: Microsoft (2023).

As previously noted, Campo Formoso is characterized by intermittent channels (Brazil, 1983). Intermittent rivers feature channels that flow during the rainy season and dry during the dry season (Christofoletti, 1980).

This dynamic in the municipality is directly linked to the semi-arid climate regime (BSh). According to the National Institute of Meteorology (INMET) (2022), the rainy season occurs from November to March, when channels have active drainage. Conversely, the dry season predominates from June to September, during which evapotranspiration significantly exceeds precipitation, resulting in intermittent or dry river channels.

Accordingly, the municipality is traversed by the Salitre River, which delineates the northern, eastern, and southern portions of the study area. The western portion is cut by the Itapicuru River, located within the Residual Plateaus complex of Serra da Jacobina (IBGE, 2009).

In terms of planning, it is important to highlight that risk assessment must consider land use and anthropogenic influences in these areas (Topázio, 2017). For this unit, monitoring of water levels in rivers and streams—particularly the Água Branca River, Mandacaru Stream, and Maria Joana Stream—is recommended, as these watercourses intersect the municipal seat.

Therefore, the implementation of measures aimed at preserving these environments is advised. One viable option is the establishment of Permanent Preservation Areas, as prescribed by the Brazilian Forest Code (Brasil, 2012b). This is justified due to problems caused by seasonal flooding in inhabited areas, which may lead to economic losses and public health concerns related to waterborne diseases (Silveira *et al*., 2021).

Conclusions

This study significantly contributes to geomorphological research in semi-arid environments, emphasizing the importance of the Campo Formoso Pediplain, which predominates in the study area. This feature—characterized by a flattened surface—is suitable for occupation but requires municipal monitoring to ensure residents' safety due to its high occupation rate.

Thus, the need for detailed studies in Brazilian semi-arid environments becomes evident, given the current research gap in the area. It is expected that this work will serve as a reference for future studies focused, for example, on mapping geotechnical risks related to urban expansion, analyzing the socio-environmental vulnerability of occupations on the pediplain, and developing geomorphological zoning proposals to support the Municipal Master Plan. Such initiatives will enable appropriate planning in tropical semi-arid environments by examining the dynamics of the predominant landforms in Campo Formoso (BA).

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