

GIS-Based Relief Compartment Mapping of Fluvio-Karst Landscape in Central Brazilian Highlands

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Abstract: The present study describes the preliminary findings of a research project aiming at creating a knowledge-base for the protection of caves heritage at Rio Vermelho preservation area in the central Brazilian highlands. A GIS-based relief compartment mapping was conducted using readily available data (e.g., satellite images, geological, and cave location maps). Four resultant geomorphological domains were identified, including (i) lowlands (282 km²) with a base-level in silicates and carbonates, (ii) the karst terrains (994 km²) which were developed in carbonates trapped by siltstone lenses, (iii) the talus (1483 km²) having colluvial and alluvial units deposited by the escarpment retreat (Urucuia Formation) and (iv) the highlands (1143.7 km²) developed over the sandstone of the Urucuia Group. The intersection of landform and geological maps resulted in delineating two abrupt contacts, the first between lowland and karst terrains and the second between the talus and highlands that formed canyon escarpment. For sustainability perspective, this study proposed two types of cave systems in the region as superior/vadose (top-bottom) that collect floods from hillslopes and deep Epigene fluvial-karst (bottom-up).

Keywords: Cave heritage, Epigene fluvio-karst, geomorphological domains, vadose cave.

Introduction

A terrain making natural geomorphic features of the earth, which results in topography, is called a landform. The landforms can be classified into three ranges as large-scale (plains, mountains), small-scale (hills, valleys) and their components (hilltops, valley bottoms, exposed ridges, flat plains, and upper or lower slopes) (Klingseisen et al., 2008; Mokarram and Sathyamoorthy, 2018). Topographic positions (hilltop, valley bottom, exposed ridge, flat plain, upper or lower slope) impact many biophysical processes taking place on earth, such as soil erosion and deposition, hydrological balance, and wind exposure. These are considered key indicators of habitat suitability, community composition, species distribution and abundance. The landforms information can be obtained using the Digital Elevation Model (DEM) analysis or field investigations (Mokarram et al., 2015).

The GIS-based classification of an area's geomorphological settings has greater importance in the landscape modeling and the consequent environmental analysis (Mokarram et al., 2015; Mokarram and Sathyamoorthy, 2018; Trentin and Robaina, 2018). Recent advancements in the GIS software lead to the adaptation of computer-based approaches for the morphometric and topographic analysis of the earth's surface. An extensively adopted GIS-based algorithm for the classification of landform is proposed by Jenness (2006) is called Topographic Position Index (TPI). It calculates the elevation difference between a central pixel and the mean elevation of its surroundings, determined based on the user-defined radii (Trentin and Robaina, 2018). This landform classification is based on

declivity (TPI) involving their applications in various fields of study such as geopedology, geomorphology and seafloor mapping, hydrology, climatology, landscape mapping, ecology and archaeology (Mihu-Pintilie and Nicu, 2019). The analysis of morphological features identification such as convexity, concavity, and flatness can provide useful information in the aquifer vulnerability assessment of the karst system and the speleological heritage preservation in the caves.

There are significant exposed carbonate areas in Brazil, mainly composed of the Precambrian rocks of the Bambuí Group. The western part of the country, which is drained by the Tocantins river, has not been studied extensively. Therefore, the present study aims at the relief compartment mapping of the karst system of the Rio Vermelho preservation area (APA NRV), part of the Corrente basin, using GIS-based analysis. This classification may help the researchers in the groundwater vulnerability assessment and the protection of speleological heritage preserved in the caves.

Study Area

The study area is located in and around the municipality of Mambá, Goiás and Brazil (Fig. 1). The site has many caves, but the prominent among them is the Tarimba cave, which is 11 km long and has several conduits and halls. The climate of the study area is tropical with well-marked dry and rainy seasons. Numerous rivers and seasonal streams are flowing in the area, such as Corrente, Vermelho and Buritis, Bezerra, Piracanjuba, Rizada, Chumbada, and Ventura (Hussain et al. 2020a, b). Rocks in the region are of Archaean, Proterozoic,

Mesozoic and Cenozoic ages. The stratigraphy is dominated by the rocks of Proterozoic age. In Brazil, most of the caves are found in the Bambuí Group. The fluvial, alluvial, and colluvial sandy deposits in the detritus-lateritic cover present the Cenozoic record (Urucuia Formation).

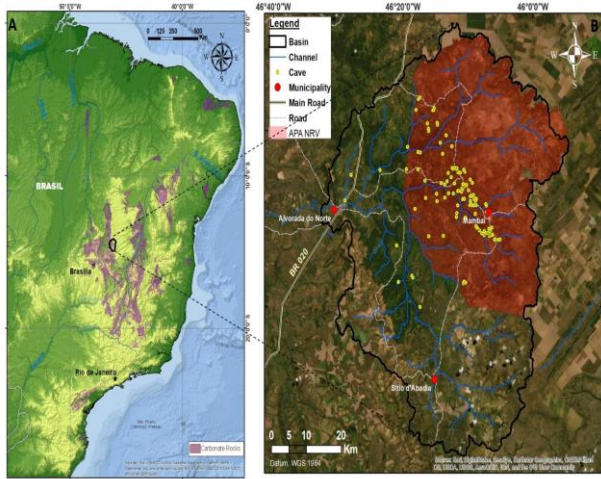


Fig. 1 (A) The location map of the study area on the map of Brazil and (B) the study area location in the Correntes basin along with the positions of the mapped caves.

The rock stratigraphy controls the soil types as Ferralsols, Arenosols and Neosols that are found in the Urucuia Group, while Cambisols/Leptosols and Acrisol (classified as Chernozem) are found in Lagoa do Jacaré Formation (Lobo et al., 2015). The retraction of the escarpment of Cretaceous sandstone (Urucuia Formation), resulted in the formation of landscapes in the region in Proterozoic Lagoa do Jacaré Formation (Bambuí Group). The Bambuí Group carbonate is very rarely exposed on the surface. It usually occurred under a layer of pelites/claystone; therefore, the area hosts a covered karst system (Fig. 2).

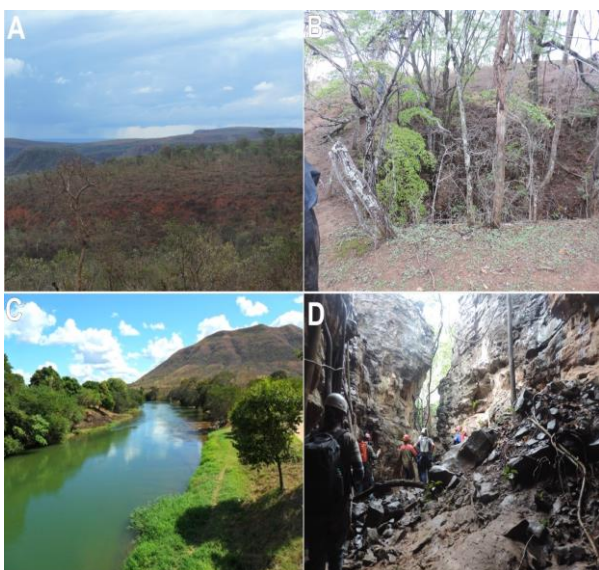


Fig. 2 The photographs of the area. From A-D: the escarpment, the very flat upper part of the sandstone, the formation of ferrassols, dolines opened in convex-concave hillslopes covered by claystone, canyons compartment formed due to cave collapse, and the lower part connected with the base level.

Materials and Methods

In the first stage, the prominent landform units were identified using the Topographic Position Index (TPI) (Jenness, 2006). Digital Elevation Model (DEM) is used at two circles with smaller and larger radii in this technique. It compares each cell's elevation in DEM with the mean elevation of a specified neighborhood region around the considered cell. The working principle of this technique has been explained in detail by Trentin and Robaina (2018). The reference DEM was obtained from ALOS PALSAR satellite data (12.5m). The landform classification proposed by Jenness (2013) was applied for the identification of prominent landform units. To divide the unity, we have used the circularity pattern, with two circles one having a smaller radius of 100m and the other larger radius of 1000m. This resulted in four landform types as canyons and deep valleys, local ridges, upland drainage and mountain tops.

In the next stage, along with the available geological map at a coarse scale, the outcomes of the in-situ investigations were taken under-consideration to better identify the level of rock outcrops and delineation of the geological contacts among different formations. In general, there was strong geological control over soil and relief; then the TPI model served to improve the lithological contacts, aggregating information to the relief unities.

In the last stage, hypsometric and the slope (in percentage) were used to improve the delineation of the abrupt contacts in the areas, especially among the compartments and canyons. In this analysis, the areas having slope value greater than 25% were used to identify the two main contacts, canyons (concentrated in the limestone) and escarpments (concentrated in the sandstone). At the end and additional step of calculating the kernel density of caves was taken using the available cave location data in order to better understand the origin of caves in context with the area's relief compartments. In this qualitative analysis, the spatial analysis tools of the ArcMap 10.8 were used.

Results and Discussion

Four landform units were identified as canyons and deep valleys (38.4% of the area), local ridges (9.36%), upland drainage (10.64%) and mountain tops (41.53 %). These units are shown in Fig. 3a. Two landform classes such as U-shaped valleys and mid-slope drainage and shallow valleys proposed in the original TPI classification were not found in the study area. On the geological map, five lithological units can be seen (Fig. 3b) out of which three controls the escarpment (Urucuia sandstone, Iron crust and silt/pelite from Bambui), one controls the talus formation (colluvium) and one controls the lowland and karst areas (Bambui carbonate). It is evident from Figures 4 and 5 that two transition zones, the canyons which mark a contact between lowlands and karst terrains (60% is slope) and the escarpments making contact between the talus and

highlands with slope values of 60% and 30%, respectively. The proposed compartmentalization to the relief of the Corrente basin is divided into Lowland (475m) in carbonates adjusted with the main river, a karst terrain (620m) formed in hanging compartments of carbonates where caves are located, a talus (730m) formed by colluvium from the escarpment retreat, the highlands, formed by the Urucua Formation, and the iron crust and pelite (805 to 1022m) (Table 1). The results of kernel density of caves show that areas of high concentration (2 caves/km²) lie near the transition zone between the karst terrains and talus (Fig. 5b), indicating that caves were formed before the erosion of the compartment and are deposited after the denudation of talus by cave tunnel and doline collapsing, and slope retraction.

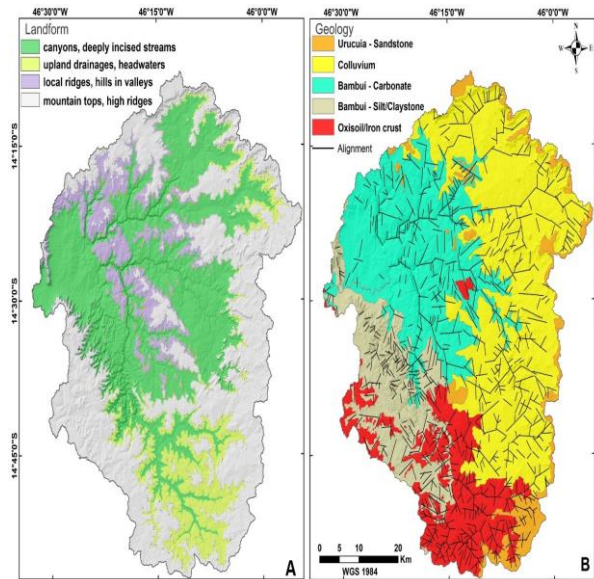


Fig. 3 (A) The landform classes resulted from TPI using the reference DEM (12.5m) derived from ALOS PALSAR satellite data, (B) Geological map along with the lineament of the area.

Two types of caves are evident, near talus vadose and meander caves and other are the paleo-karst system filled with sediments (Fig. 5b). The caves near the canyons are linear, phreatic and with no sediments that indicate their fluvial-karst origin of the vadose caves that collect floods from hillslopes (ducts are often found filled with paleo-sediments having signs of paragenesis), and the other deeper epigone fluvial-karst regions.

Table 1. Different characteristics of the identified relief compartments in the study area.

Class	Area (km ²)	Elevation (m)	Average slope (%)	Drainage density (d/km ²)
Lowlands	282.9	470-620	5	0.21
Karst terrains	994.6	620-730	9.5	0.23
Talus	1483	730-800	7	0.10
Highlands	1143.7	800-1022	3	0.12

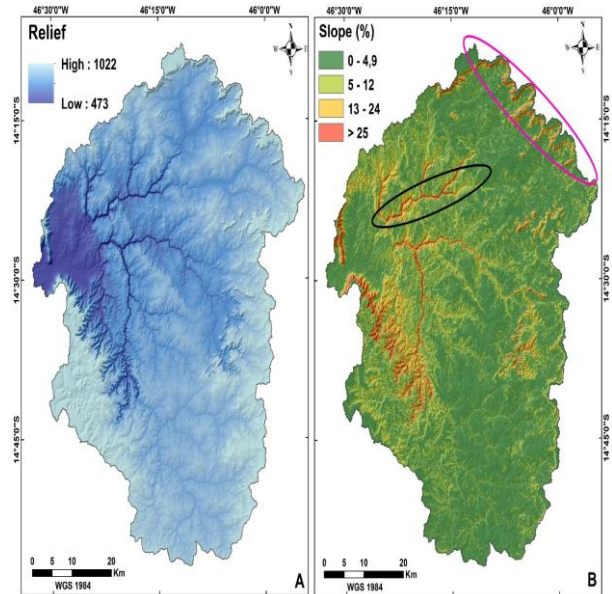


Fig. 4 (A) Relief value map and (B) slope in percentage. The black ellipse marks the canyons area, and the purple ellipse highlights the escarpment area.

The caves are operating to open canyons valleys in rectangular drainage. The limestone is covered by the siltstone lens, which may generate gentle slopes in the area, even at the places where drainage are inside the caves. The nearby sandstone aquifer may be the source of sediments for the cave.

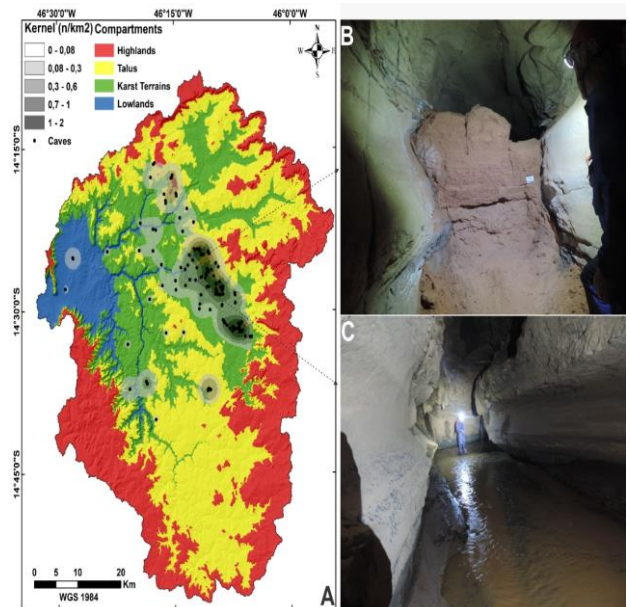


Fig. 5 (A) Different landform units along with the kernel density function (caves per square kilometer) of mapped caves in the area, (B-C) photographs showing two types of caves, near the talus there are vadoze and meander caves, filled with sediments, while caves near the canyons represent the fluvio-karst, being linear and phreatic, without having sediments.

Conclusion

The present study was carried out for the relief compartment mapping of an environmentally sensitive area of Brazil. Four relief compartments along with two

abrupt contacts are identified in the area. The karst of the area buried under a layer of claystone/pelite, hence formed covered karst. This claystone layer may control the occurrence of concavities without having exposed channels in the area. The integrated multidisciplinary approaches, including hydrology, geochemistry, sedimentology, geochronology, and geophysics, are recommended. In this way, better future plans for the sustainability of this area can be fulfilled.

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