An introduction and GIS-based relief compartment mapping of fluvio-karst landscape in central Brazilian highlands

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Abstract

The present work is part of a greater research project aiming at creating knowledge-base for the future managerial plans dedicated to the protection of caves heritage in the Correntes Basin (3904 km^2) located in the central Brazil. Here, a GIS-based relief compartment mapping of the area is done using satellite images, geological and cave location maps as input data layers. As a result four geomorphological domains were identified as i) lowlands (282 km^2) with a base-level in silicates and carbonates, ii) the karst terrains (994 km^2) which were developed in carbonates trapped by siltstone lenses iii) the talus (1483 km^2) having colluvial and alluvial units deposited by the Urucuia escarpment retreat and iv) the highlands (1143.7 km^2) developed over the sandstone of the Urucuia Group. The intersection of landform and geological maps resulted in delineation of two abrupt contacts, the first between lowland and karst terrains, and second between the talus and highlands which formed canyon and escarpment, respectively. Two types of the cave systems are proposed in the region as superior/vadose that collect floods from hillslopes and deep epigene fluvio-karst.

Keywords: cave heritage; epigene fluvio-karst; geomorphological domains; vadoze cave

1 Introduction

A terrain making natural geomorphic feature of earth, the arrangement of which results in topography is called landform. The landforms can be classified into three ranges as large-scale (plains, mountains), small-scale (individual 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 etc.) have impact on the many biophysical processes taking place on the earth such as soil erosion and deposition; hydrological balance and wind exposure etc. Therefore, they are considered as key indicators of habitat suitability, community composition, and species distribution and abundance. The landforms information can be obtained either using Digital Elevation Model (DEM) analysis or by field investigations (Mokarram et al. 2015).

The GIS-based classification of the geomorphological settings of an area 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 softwares lead to the adaptation of computer based approaches for the morphometric and topographic analysis of the earth 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 which is determined using user defined radii (Trentin and Robaina, 2018). This landform classification based on declivity (TPI) involving their applications in various field of study such as geopedology, geomorphology and seafloor mapping, hydrology, climatology, landscape mapping and ecology, and archeology (Mihu-Pintilie and Nicu, 2019 and references therein). 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 in the speleological heritage preservation in the caves.

There are big exposed carbonate areas in Brazil mainly composed of the Precambrian rocks of 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 Corrente basin using GIS based analysis. This classification may help the researchers in the groundwater vulnerability assessment and the protection speleological heritage preserved in the caves.

1.1 Study area

The study area is located in and around the municipality of Mambaí (Figure 1). The area has many caves but more prominent is the Tarimba cave which is 11 km long and has several conduits and halls. The climate of the region is tropical with dry and rainy seasons. The surface hydrology constitutes numerous rivers such as the Currente, Vermelho and Buritis. The main streams are Bezerra, Piracanjuba, Rizada, Chumbada and Ventura. It also has many depressions commonly called *grotta* which are filled with rain water and may form the drainage network depending on the amount of rainfall. Some of the watercourses penetrate into the soil becoming subterranean and their re-emergence at the surface promoting the formation of caves. The northeastern region of the State of Goiás has several geomorphological domains. Their features are evident from the morphostructure resulted from the climate change as dissected contrasts and recessed forms the conserved forms, which represent remnants of the oldest topography. It is drained by the Paraná and Maranhão Rivers, which form the Tocantins River. In the northeast region of the State of Goiás, the following soil classes are found: latosols, podzolic, cambisols, plinthsol, gleysol, sands hydromorphic quartzs, organic soils, quartz sands, alluvial soils, soils litholic, petroplinthic soils (Lobo et al. 2015).

The northeast region of Goiano presents lands with stratigraphic records of the Archaean, Proterozoic, Mesozoic and Cenozoic, most of which are Proterozoic, which include the following units: Ticunzal formation, sequence volcanic-sedimentary rocks of Palmeirópolis and São Domingos, Arai Group, Serra Branca, Tonalito São Domingos, Paranoá Group and Bambuí Group. The most extensive carbonate unit is the Bambuí Group, which hosts the largest number of caves in Brazil (Auler, 2002). The Urucuia formation representing continental fluvial deposition, restricted to the eastern portion of the area, attributed to the Cretaceous land of Mesozoic age. The Cenozoic is found in the current fluvial deposits, alluvial and colluvial sandy deposits and in the detritus-lateritic cover.

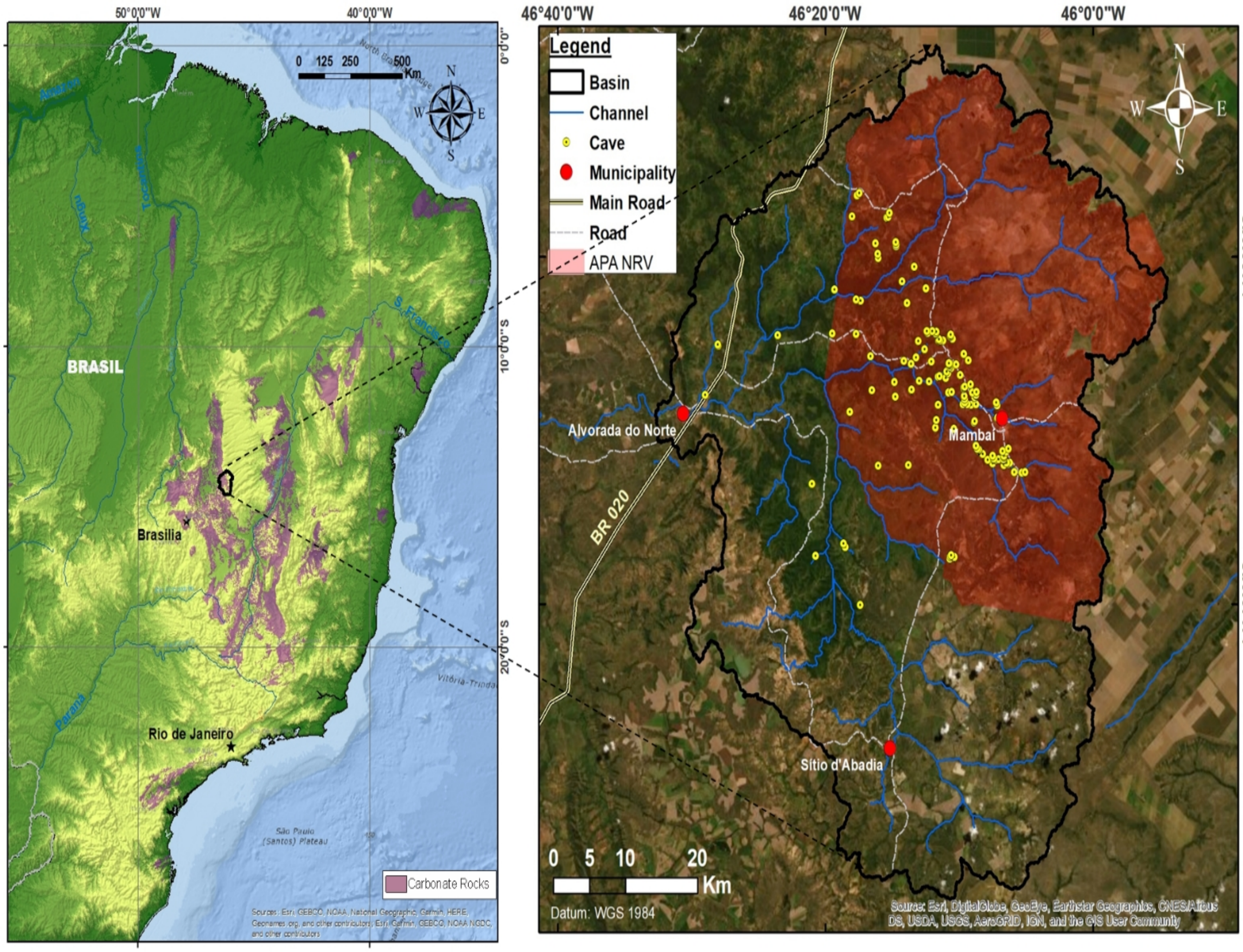

Figure 1 (a) The location map of the study area on map of Brazil and (b) study area in the Correntes Basin along with the positions of the mapped caves.

The landscapes in the area are formed by the retraction of the escarpment of Cretaceous sandstone (Urucuia formation), over carbonates and pelites of the Proterozoic *Lagoa do Jacaré* formation (Bambuí group). It is important to note that the Bambuí group carbonate is found rarely exposed on the surface, it usually occurred under a layer of pelite. Therefore, the study area hosts a covered karst system (Fig. 2).

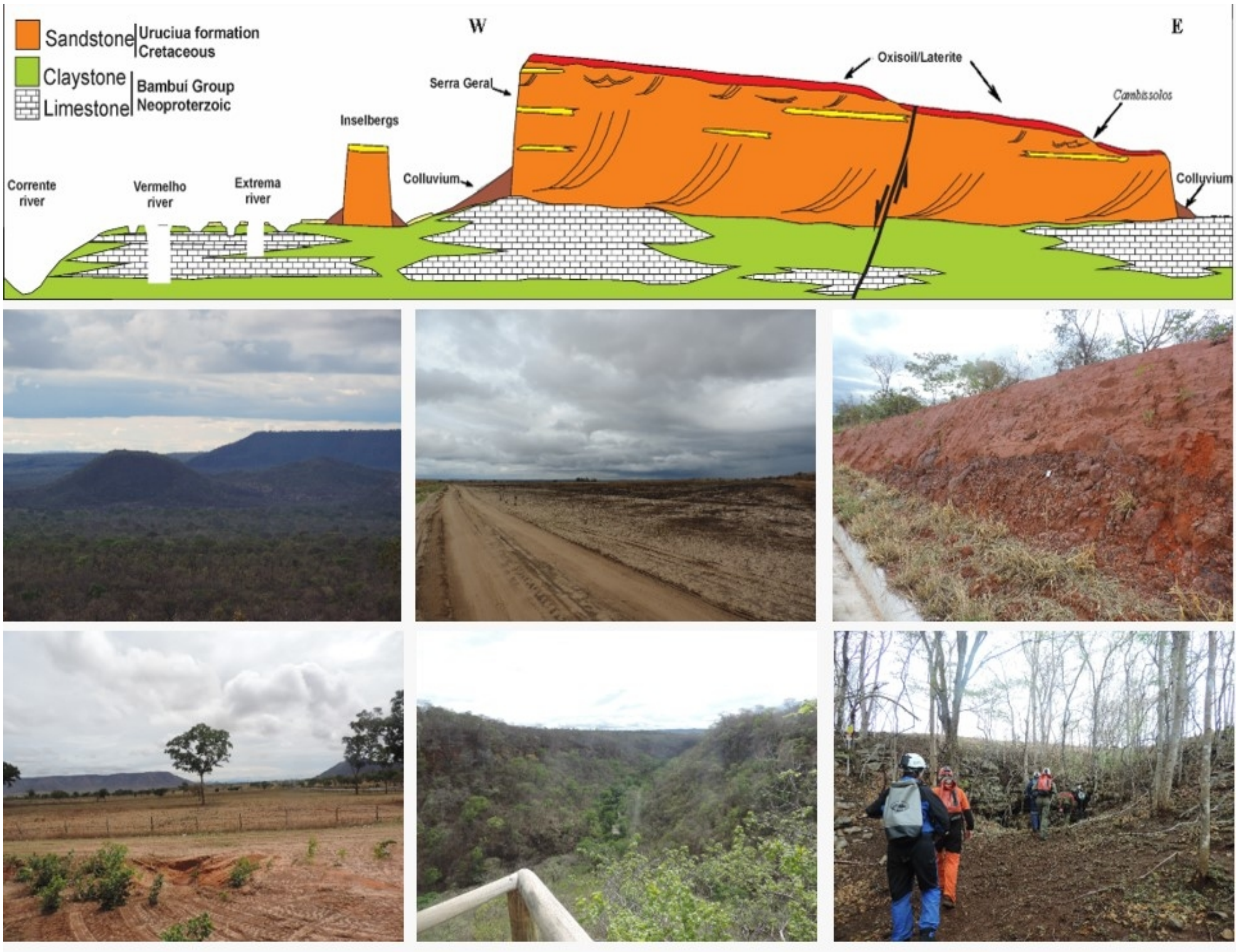

Figure 2 (a) Conceptual model of the area showing the formation of caves and stratigraphy of the area. The photographs of the area. The first row (left to right): the escarpment, the very flat upper part of the sandstone, the formation of oxisoil. Second row: dolines opened in convex-concave hillslopes covered by claystone, canyons compartment formed as result of cave collapse and the lower part connected with the base level.

2 Material and Methods

In the first stage, the prominent landform units were identified using a Topographic Position Index (TPI) calculation proposed by Jenness (2006). In this technique, Digital Elevation Model (DEM) is used at two circles with smaller and larger radii. It compares the elevation of each cell 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 details by Trentin and Robaina (2018).

In the next stage, the TPI driven landform was intersected with geological maps (CPRM 1:1000.000 scale) because of the strong geological control over the units. This resulted in relief compartment map of the area. Along with the available geological map at coarse scale, the outcomes of the in-situ investigations were taken under-consideration for the better identification of the level of rocks outcrops and delineation of the geological contacts among different formations. In the last stage, slope (%) and hypsometric maps were used for the batter delineation of the abrupt contacts especially, among the compartments and canyons. An additional step was taken where karnel density of caves was calculated from the available cave locations data in order to understand the origin of caves in context with the relief compartments of the area.

3 Results and Discussions

As a result of TPI, 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 that are 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 Fig. 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 the 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 Urucuia formation, and the iron crust and pelite (805 to 1022m). Table 1 has the details. The results of kernel density of caves showed that areas of high concentration (2 caves/km^2) 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.

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

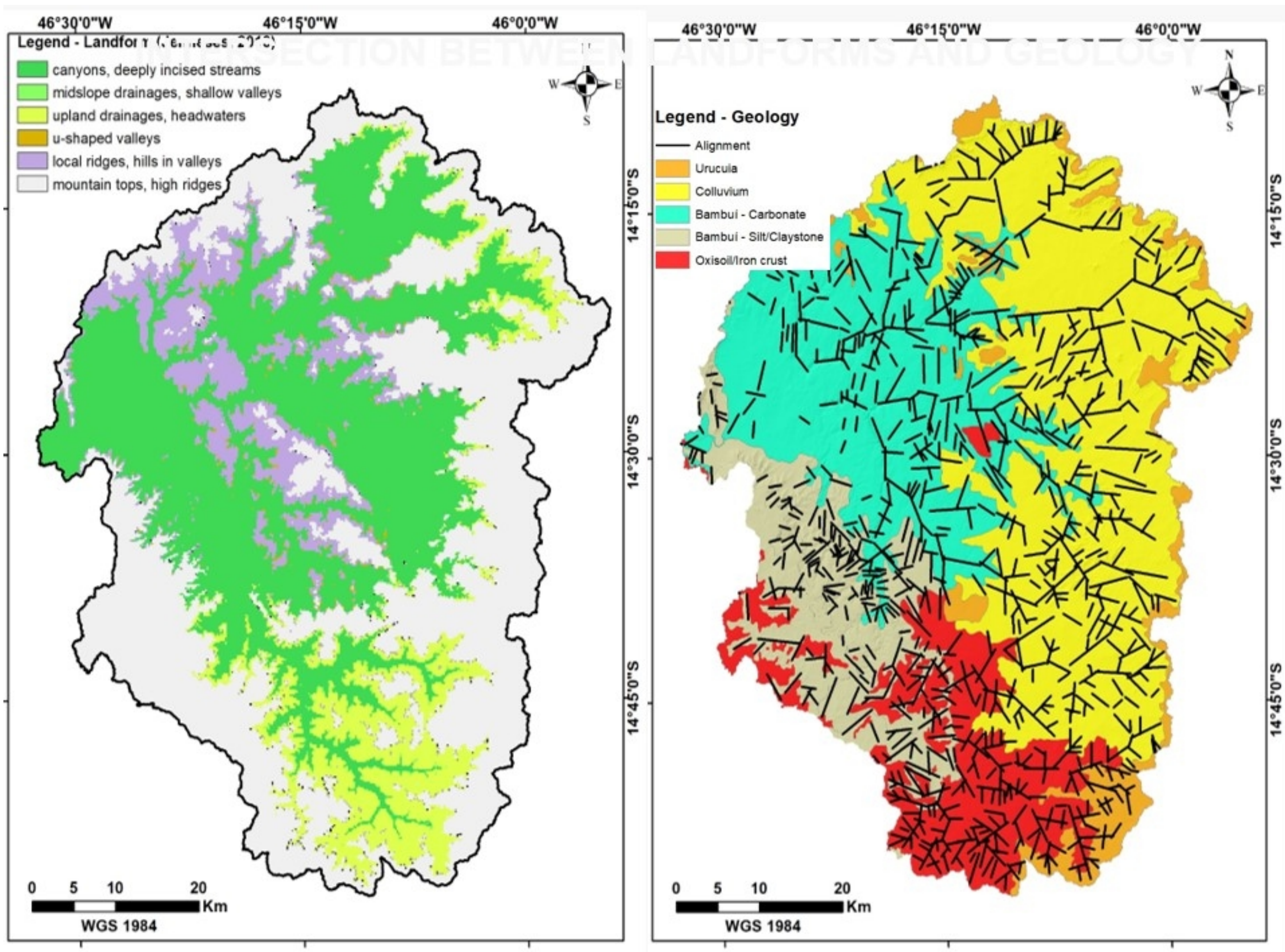

Figure 3 (a) The landform classes resulted from TPI using the reference DEM (12.5m) derived from ALOS PALSAR satellite data, (b) Geological map along with the lineament of the area.

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

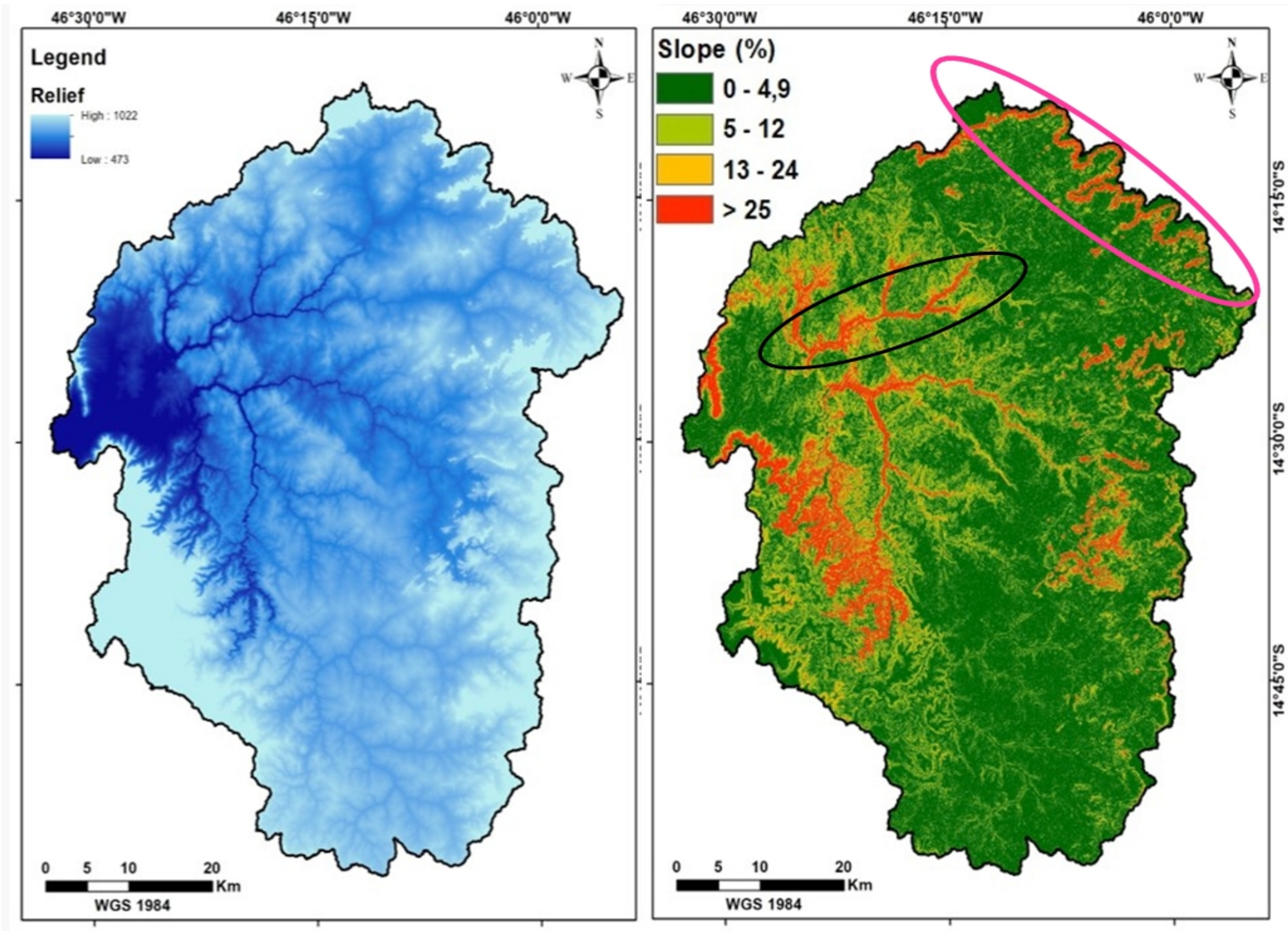

Figure 4 (a) Relief value map and (b) slope (%). The black ellipse shows the canyons area and the purple ellipse shows the escapement area.

The caves are operating to open canyons valleys in a 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 standstone aquifer may possibly be the source of sediments for the cave.

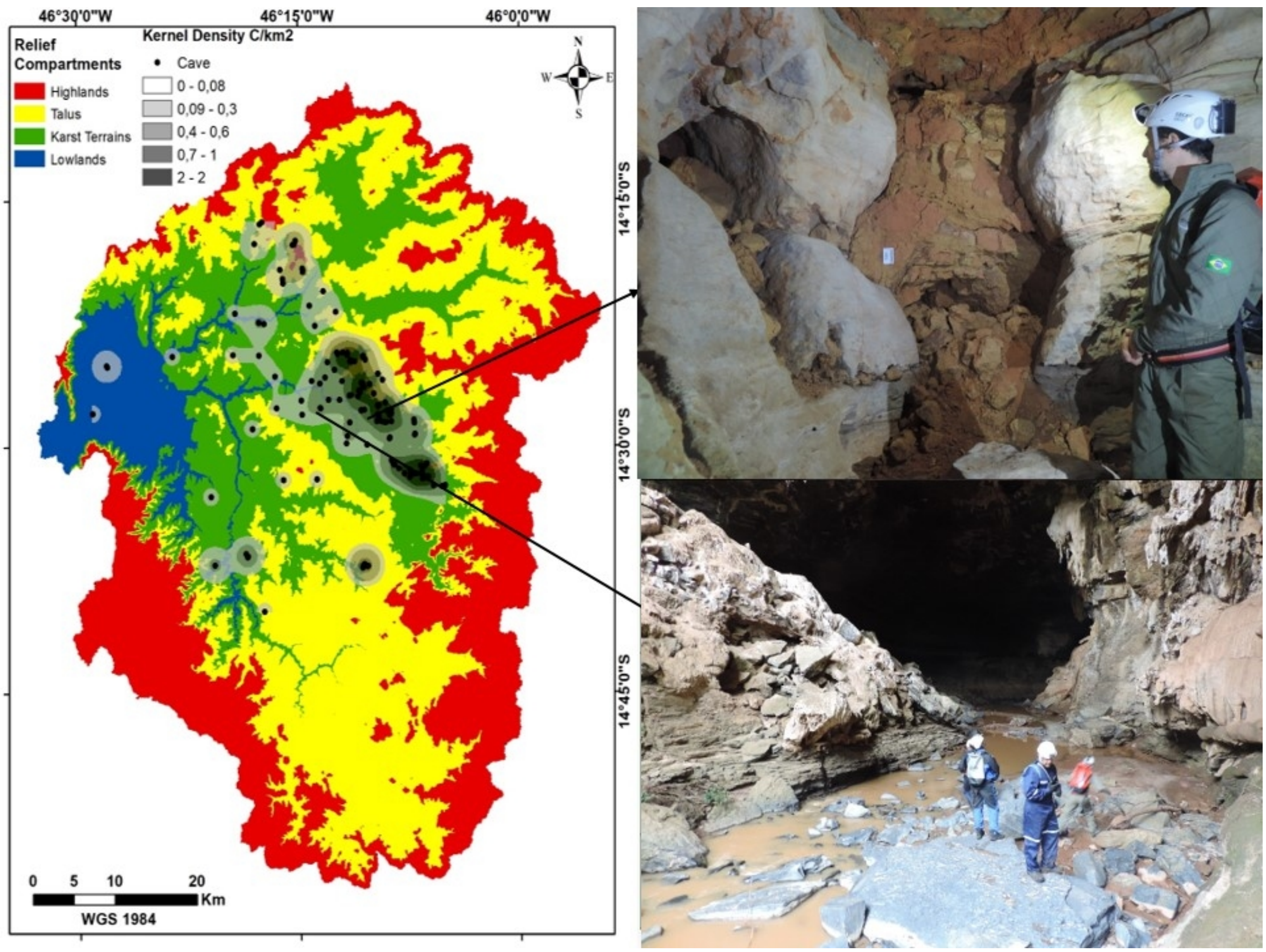

Figure 5 a) Different landform units along with the kernel density function (caves per square kilometer) of mapped caves in the area, b) photographs showing two types of caves, near the talus there are vadoze and meander caves, filled with sediments, while caves near the canyons represent the fluvio-karst,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

4 Conclusions and Recommendations

The present study was carried out for the relief compartment mapping of an environmentally sensitive area of Brazil. The following conclusion are drawn.

Four relief compartments along with two abrupt contacts are identified in the area. The Lowlands (282.9 km^2): from 470 to 620m ASL representing the base-level in siltstone and carbonates. This unit has an average slope value of 5% and drainage density is 0.21 d/km^2. About 0.32% of the area is covered with concavities. It is predominated with hydromorphic soils. The karst terrains (994.6km^2)

from 620 to 730m ASL developed in carbonates trapped by siltstone lenses, average slope of 9.5%, 0.23% of concavities, and drainage density is 0.22 d/km^2. The talus (1483 km^2) from 730 to 800 ASL with colluvial and alluvial deposits formated by the Urucuia escarpment retreat, average slope of 7%, 0.10% of concavities, and drainage density in 0.26 d/km^2. The highlands (1143.7 km^2) from 800 to 1022 ASL, formated over the sandstones of the Urucuia group whit average slope of of 3%, 0.12% of concavities, and drainage density in 0.30%. The lowlands and karst terrains have concavities (22%) while the talus and highlands are concentrated in the major parts of perennial drainage. It suggests the presence of the karst under claystone give rise covered karst. The claytone controls the occurrence of concavities without having exposed channels in the area.

The underlying hypothesis is about the sandstone aquifer and the presence of siltstone are the sources of water and silty sediments for the caves, respectively. This can be tested with the application of integrated multidisciplinary approaches such as hydrology, geochemistry, sedimentology, geochronology, and geophysics. In this way, better future planes for the sustainability of this area can be done. Therefore, the detailed future analysis including massive hydrological, geochemical, sedimentological, geochronology and geophysical are recommended. In this way, a better future managerial plans for the sustainability of the environment of the area can be done.

Conflicts of Interest: Authors declare no conflicts of interests.

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