APPLICATION OF THE CONCEPT OF GEOMORPHONS TO THE LANDFORM CLASSIFICATION IN TOCANTINS STATE, BRAZIL

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APLICAÇÃO DE *GEOMORPHONS* PARA A CLASSIFICAÇÃO DO RELEVO NO ESTADO DO TOCANTINS, BRASIL

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Abstract: This paper presents a classification system for landform elements. The classification and mapping methods for landform elements with a DEM are based on the principle of pattern recognition and the concept of geomorphons. These elements are classified using a relative classification model based on surface shape and position. We identified 13 different landforms units in Tocantins state in the northern region of the Amazon based on the definition of the dominance and relationship of the geomorphon elements. The developed geomorphon maps are a valuable new resource for both manual and automated geomorphometric analyses. In Tocantins state, this method allowed the classification of units that correspond to geomorphologically-recognized features.
Keywords: DEM, Geomorphology, Modelling,

Resumo: Este trabalho apresenta um sistema de classificação de elementos do relevo. O método de classificação e mapeamento para elementos do relevo utiliza MDE e se baseia no princípio de reconhecimento de padrões e conceitos de *geomorphons*. Estes elementos são classificados utilizando um modelo de classificação relativa, baseada na forma da superfície e posição dos elementos. Foram identificados 13 diferentes unidades de relevo no estado de Tocantins, localizado na região norte, na Amazônia legal, com base na definição do domínio e da relação entre os elementos de *geomorphons*. Os mapas de geomorphons desenvolvidos são um novo e valioso recurso tanto para análise geomorfométrica manual e automatizada. No estado de Tocantins, este método permitiu a classificação das unidades que correspondem às feições geomorfológicas reconhecidas.

Palavras Chaves: MDE, Geomorfologia, Modelagem

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APPLICATION OF THE GEOMORPHONS TO THE LANDFORM CLASSIFICATION IN TOCANTINS STATE, BRAZIL

1.INTRODUCTION

This work presents the classification and mapping of landforms based on the concept of geomorphons that represent an elementary unit of the terrain. Landform studies based on morphometric parameters are widely used to obtain information about the dynamics of the landscape and are of great importance for geomorphological studies.

The parameterization of the morphology of the relief through Geographic Information System (GIS) uses the process of extracting quantitative topography attributes and describing the Earth's surface forms with equations applied to numerical altimetric models (MUÑOZ, 2009). Geomorphologists carried out a significant amount of work using GIS to automatically extract terrain information from digital databases. Wood (1996) and Schmidt & Dikau (1999) have discussed different aspects of this type of research, indicating that relief information is important for landscape classifications.

The present classification methods allow the division into landform elements, which are a group of relatively homogeneous types of landforms (MACMILLAN; SHARY, 2009). According to Hengl; Reuter (2009), most applications use geomorphometric rectangular grids to shape the data used in digital elevation models (DEM).

Drăguţ; Blaschke (2006) chose to target relatively homogeneous objects at various geomorphological levels using elevation models and plan curvature and vertical curvature.

Iwahashi; Pike (2007) presented an automated topographic classification method without supervision based on three morphometric variables: steepness, convexity of the slopes and surface texture.

Recently, Jasiewicz; Stepinski (2013) established a landform elements classification using tools of computer vision. The authors make an analogy for the textural classification image based on the spatial arrangement of shades of grey for a given region's spatial arrangement of elevation. They used the concept of 'local ternary patterns' (LTP) (LIAO, 2010) to identify the landform elements, which are called geomorphons by analogy to textons (JULESZ, 1981). Textons refer to basic micro-structures in an image and constitute the core elements of visual perception (JULESZ, 1984). Similarly, geomorphons are fundamental relief microstructures. Thus, landform maps can be used as algorithms.

The medium algorithms can classify and map elements in landforms using computational techniques. Landform elements can be expressed by a number of different geomorphons that can be represented by the 10 most common elements: flat, peak, ridge, shoulder, spur, slope, hollow, footslope, valley, and pit (JASIEWICZ & STEPINSKI, 2013). In order to demonstrate a practical application of geomorphons method we applied it to generate a geomorphometric map of the country of Poland. The spatial extents of these varied landscapes are identifiable as coincides with physiographic partition of Poland.

The purpose of this study is to dominance and relationship of the geomorphon elements were used to determine the different landforms in the state of Tocantins in the Brazilian Amazon area.

2.STUDY AREA

The Tocantins state area represents 3.26% (277,620 km²) of the Brazilian territory with approximately 97.9% of the total area of the state in the Amazon. (Figure 1). The climate is humid to sub-humid with a moderate water deficit. Geologically, the state consists of large areas of sedimentary unconsolidated deposits in the west on landforms of the food-plain, sedimentary rocks of intracratonic basins in the east, with the development of landforms such as plateaus, mesas, and buttes, and metamorphic and igneous rocks of the mobile belts and crystalline basement in the centre–south, including landform elements with faults and folds producing ridges, narrow valleys, plateaus and hills. (SECRETARIA DE PLANEJAMENTO DO ESTADO DO TOCANTINS (SEPLAN), 2012).

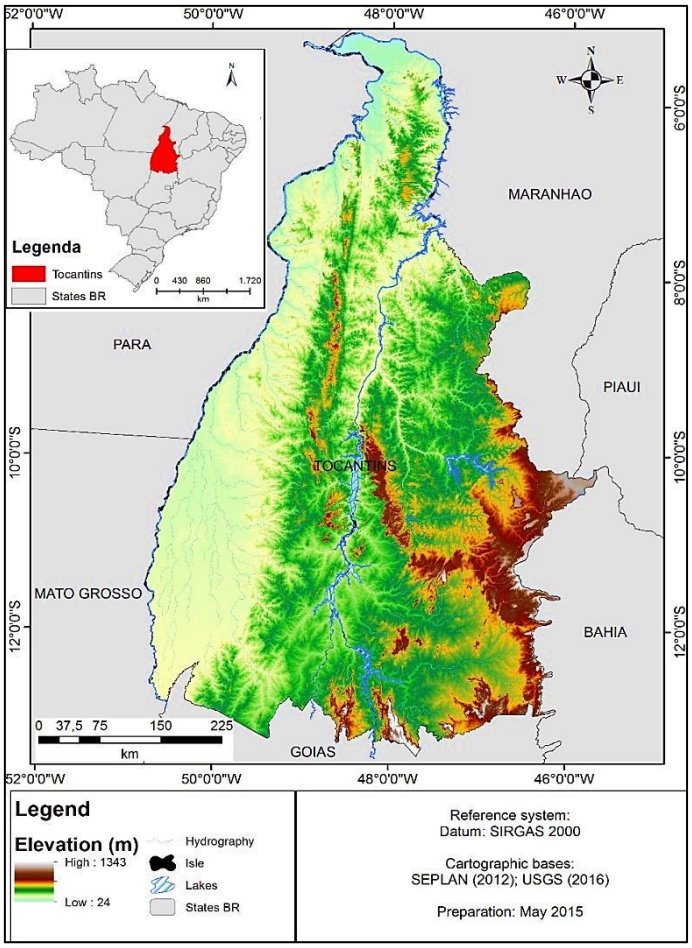

Figure 1. Location of Tocantins state, Brazil. Org.: The authors.

3.METHODOLOGY

The cartographic databases used in this work were made by the political–administrative boundary of the state of Tocantins, provided by the Instituto Brasileiro de Geografia e Estatística (IBGE), 2010), which defined the boundaries of the study area and are also based on the original digital elevation model Shuttle Radar Topography Mission (SRTM) provided by the United States Geological Survey (USGS), with a spatial resolution of 3 arc-seconds (90 metres) (KRETSCH, 2000). The study and representation scale was 1:100.000.

The methodology used for the definition of the geomorphons is based on the proposal of Jasiewicz & Stepinski, (2013). The authors analyse the textural similarity of the DEM, which presents the variation of the grey levels between neighbouring cells considering a specific level and transfers the terrain elevation values, where most is "1", less is "-1", and equal is "0" (Figure 2).

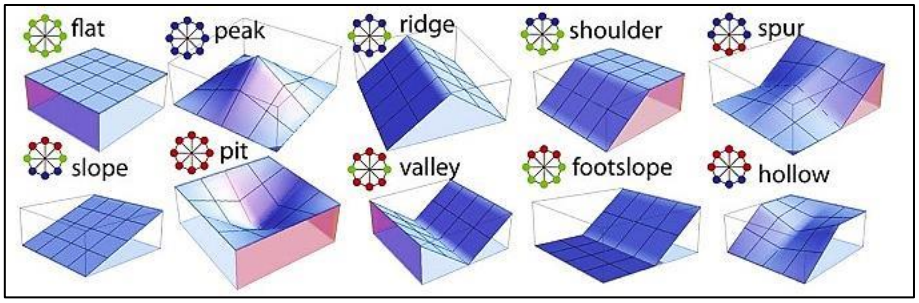

Figure 2. Main geomorphons known for the analysis of the landforms. (JASIEWICZ; STEPINSKI, 2013).

For this calculation, profiles are established for the main directions from the central cell 'lookup distance', L, which was extracted from the digital elevation model (JASIEWICZ; STEPINSKI, 2013).

We used an online application for the realization of the processing in DEM and the generation of geomorphons, available at <<http://sil.uc.edu/geom/app>>. The application code is also available for download at <<http://sil.uc.edu/>>.

The application requires a set of raster data and two scalar values such as free parameters. The input file for the is an MDE based on the original digital elevation model Shuttle Radar Topography Mission (SRTM) provided by the United States Geological Survey (USGS), with a spatial resolution of 3 arc-seconds (90 metres) (KRETSCH, 2000).

The two free parameters are lookup, L (distance in metres or cell units), and threshold, t (levelling in degrees). The L value of 20 pixels (1800 metres) and t of 2 degrees were applied to the free parameters.

The compartmentalization of landforms was performed using the manual grouping of the main elements as their spatial distribution.

4.RESULTS

The spatial scales of these varied landscapes are identified in Figure 3, with different patterns of colours representing the geomorphons elements that can be represented by the 10 most common elements: flat, peak, ridge, shoulder, spur, slope, hollow, footslope, valley, and pit. The relief in Tocantins state is characterized by flat elements that comprise 61% of the geomorphons identified. The slope and footslope elements are also important (16%), but they occur mainly in the central portion and on the eastern edge of the state.

The results of the landforms mapping in Tocantins state for the distribution of the geomorphons elements showed 13 landforms units, obtained from the observation of the predominance and association of these elements, represented schematically in the blocks diagrams of the figures 6 e 7. The percentage distribution is described in Table 1 and Figures 4 and 5.

Landforms unit 3 occupies the largest area in the state, followed by landforms units 7, 1 and 2. In relation to the geomorphons elements, the landforms units 1, 2 and 3 predominantly amplify flat elements. However, in addition to the flat element, slope and footslope elements are important in unit 7. The landforms unit 5 shows a specific area located NW of the state.

The landforms units identified were related to the map of geomorphological Domains and Units of the state of Tocantins developed by SEPLAN (2012).

Table 1. Areas and percentages occupied by landform units in Tocantins state:

Landform units	Area km²	Percentage
Unit 1	43889.74	15.78
Unit 2	42221.12	15.18
Unit 3	76511.32	27.51
Unit 4	10961.43	3.94
Unit 5	276.28	0.10
Unit 6	4120.45	1.48
Unit 7	44596.43	16.04
Unit 8	15176.45	5.46
Unit 9	1356.58	0.49
Unit 10	5294.65	1.90
Unit 11	17400.25	6.26
Unit 12	3194.34	1.15
Unit 13	13086.43	4.71

Org.: The authors.

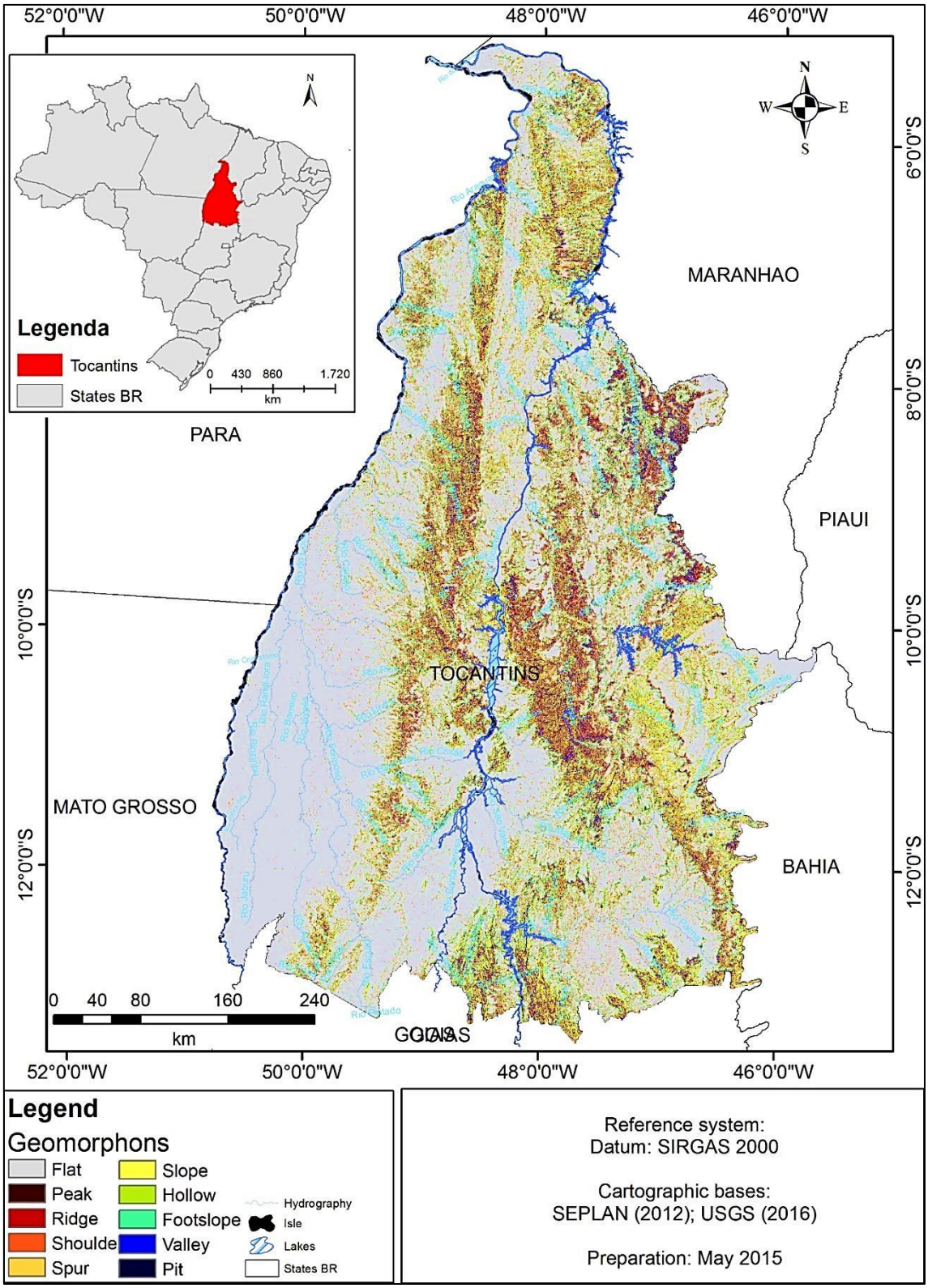

Figure 3. Spatial distribution of geomorphons elements in Tocantins state. Org.: The authors

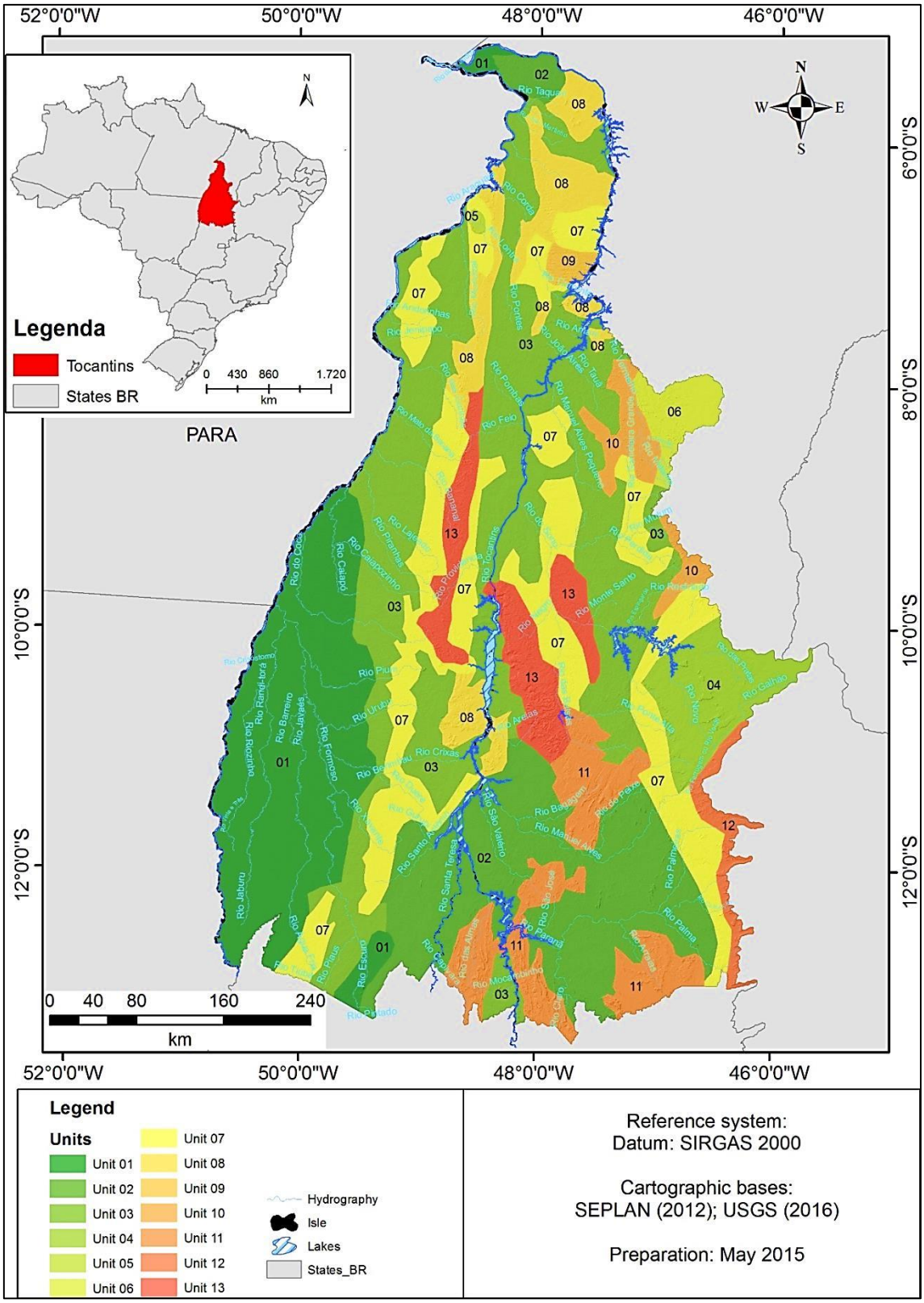

Figure 4. Landform units in Tocantins state. Org.: The authors

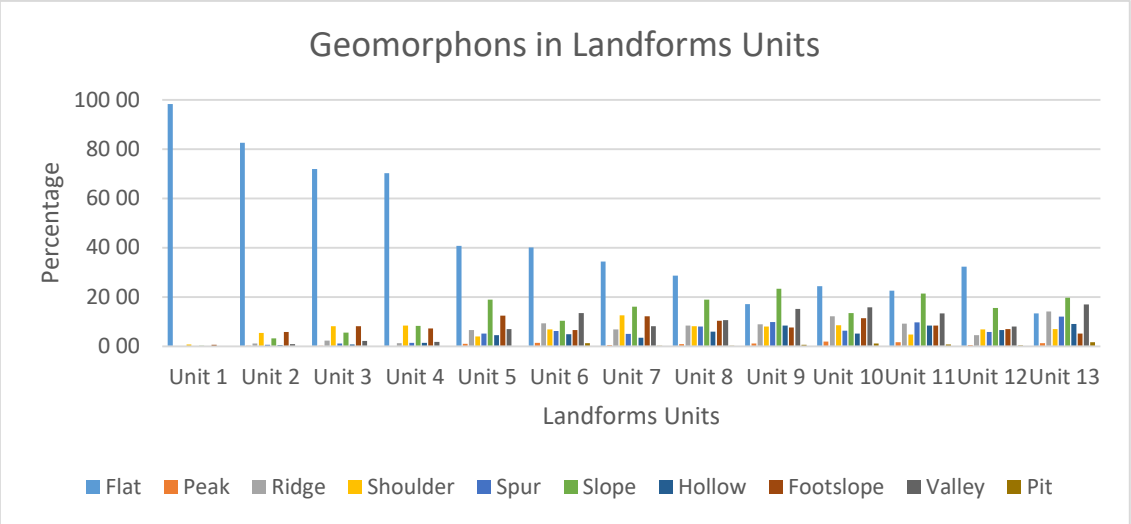

Figure 5. Percentage of geomorphons elements present in each landform unit in Tocantins state. Org.: The authors

Unit 1

The unit consists of geomorphons elements of flat areas, with 98.3% occurring in associated areas of flood plains, schematically shows the characteristics of the landforms in that unit (figure 6).

It is a large area in the western and extreme northwestern part of the state at the confluence of the Araguaia and Tocantins rivers. Geomorphologically, it is associated mainly with *Araguaia Plain* with substrate-unconsolidated sedimentary deposits.

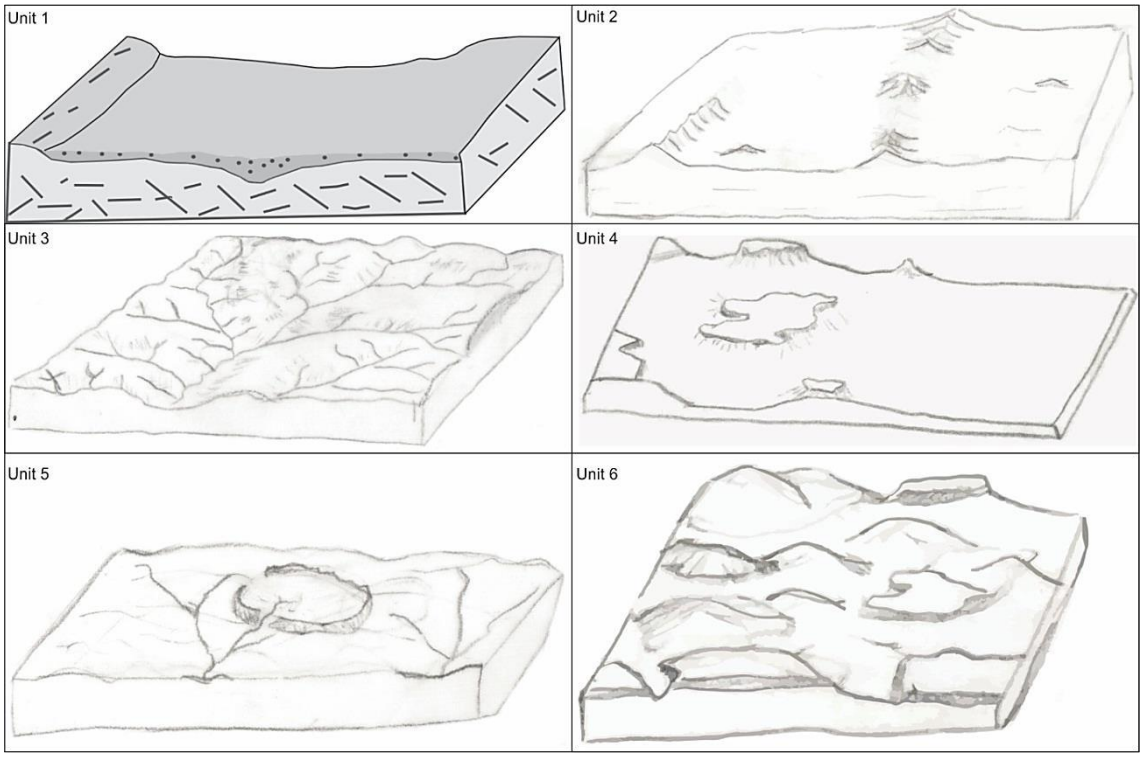

Figure 6. Schematic representation of the landforms of units 1 to 6. Org.: The authors

Unit 2

This unit is characterized by flat geomorphons elements (82,6%) and the presence of footslopes and shoulders (> 5%). The main differences with respect to unit 1 are the presence of the shoulder and footslope elements. The schematic drawing in figure 6 shows the characteristic relief of this unit.

The relief occurs in a large area in the southern and southwestern part of the state and also in a small area to the north. Geomorphons elements that make up this unit are well represented in the geomorphological domains of *Alto Tocantins and Imperatriz Depression*.

Unit 3

This unit includes two large territorial areas of the state, representing a slightly undulated relief, dissected and represented by flat geomorphons elements (71.8%), shoulders and footslopes (8% each), and slopes (5%). The shoulder and footslope elements are more significant than in the previous unit, being that the shoulders are represented by outcrops of rocks. In Figure 6 is observed the schematic drawing with characteristic landforms of this unit.

One area of the unit covers a land strip running southwest, east, and northwest of the state, which is associated with the geomorphologic domain of the *Middle-Low Araguaia Depression* with metasedimentary substrates. Another area covering the central and northeastern parts of the state is geomorphologically associated with *Middle Tocantins Depression* with sedimentary basin substrates.

Unit 4

This unit covers a large area located in the eastern part of the state, the Jalapão region, which is characterized by an extensive flat area covering 70.2%, with an elevation of flat tops that are marked by a shoulders (8.4%), steep slopes (8.2%), and footslopes (7.1%). The geomorphons elements flat is less important and shoulder more important compared to unit previous. The schematic drawing in figure 6 shows the landform characteristics of this unit.

The geomorphologic domains, which represent these geomorphons elements, are *Mangabeira Chapadas*[5] *and Cliffs* with sedimentary basin substrates, consisting of sedimentary rocks. The greater erosive resistance of the sedimentary layers maintains the shape of the relief.

Unit 5

This unit is restricted to a small area represented by isolated elevations in a dissected area located in the northwestern part of the state. The geomorphons elements that define the area are flat, with footslopes and semicircular slopes (40.6%, 18.8%, and 12.4%, respectively). Presents the most significant footslope elements compared to the other units. The landform characteristics of the unit is shows in schematic drawing (figure 6).

This unit is in the geomorphological domain of *Andorinhas - Xambioá – Lontras Sierras* with metasedimentary bedrock.

Unit 6

This unit covers a large area in the northeast of the state that is characterized by a large area with elevations of flat tops and deep valleys. The geomorphons element characteristics are flats (40%) and valleys with (13.4%) slopes (10.3%) and ridges (9.2%). The schematic drawing in figure 6 shows the landform characteristics of this unit.

This unit corresponds to the geomorphological unit of *Alto Parnaíba Chapadões*, which is composed by sedimentary rocks that are cut by a major system of fractures and are the valley elements.

Unit 7

This unit is characterized by geomorphons element that are flat (34.4%), slopes (16.1%), shoulders and footslopes (approximately 12%) and valleys (8.1%), show in schematic drawing in figure 7.

[5] Chapada – Plateau develop on horizontal strata.

The geomorphons elements that define this unit occur more significantly in a strip that follows the centre–western part of the state associated with the Geomorphologic Domain *Cristalândia Depression,* which comprises metasedimentary rocks, and the *Interfluve Tocantins-Araguaia Plateau* with resistant sedimentary rocks. There is also a narrow strip located in the eastern part and southwest of the state covering the geomorphological Domains *Mangabeiras Cliffs* and *Baiano Ocidental Cliffs and Chapadões* with sedimentary basin substrates.

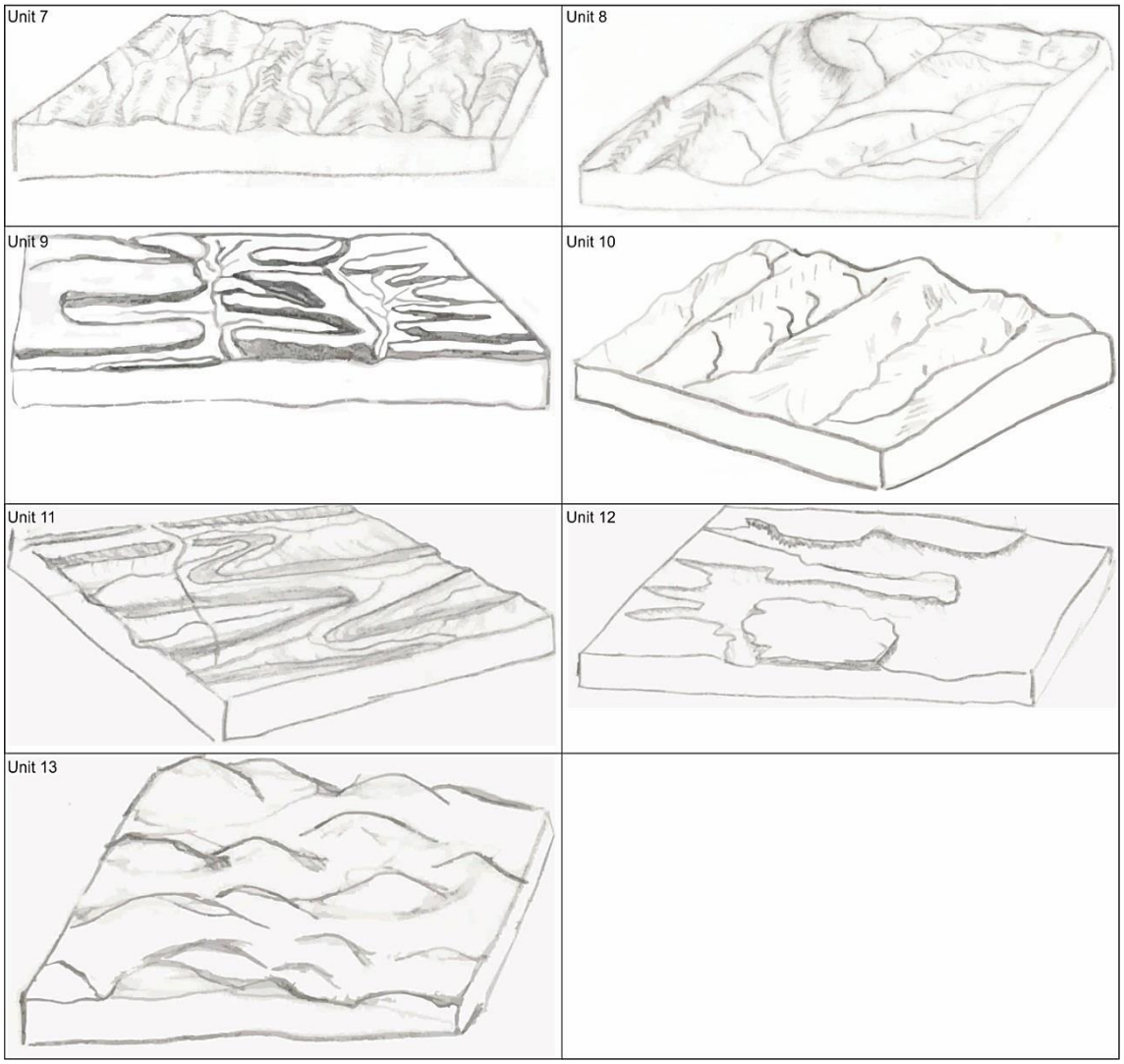

Figure 7. Schematic representation of the landforms of units 7 to 13. Org.: The authors

Unit 8

This unit comprises an association of flat elements (28.6%), slopes (18.9%), footslopes and valleys (> 10%). The schematic drawing in figure 7 shows the landform characteristics of this unit. This geomorphons element association is distributed across a small area of the central part of the state and in many other areas in the northern part.

The first occurs in a relatively high region, which is associated with geomorphological domains of the *Serra Malhada Alta* with substrates of crystalline basement rocks and the Serra do Santo Antonio with metasedimentary rocks. In the northern part, this unit is associated with the geomorphological domains of the *Imperatriz Depression, Porto Franco–Fortaleza dos*

Nogueiras Cliff, Medio Tocantins Depression, Interfluve Tocantins–Araguaia Plateau and Araguaia Cliffs. These domains have sedimentary rock substrates of the sedimentary basins.

Unit 9

This unit is limited to a small portion in the NE of the state, and the geomorphons elements that define this unit are slopes (23,3%), flats (17.1%), ridges, shoulders, hollows and footslopes, as well as valleys that are engaged and oriented EW (15.1%), with the schematic drawing in figure 7 shows the landform characteristics of the unit.

This unit is included in the geomorphological domain called *River Farinha Chapadas* composed of sedimentary rocks resistant to erosion and valleys following structural lineaments.

Unit 10

This unit covers two areas of the northeastern part of the state and is characterized by a combination of geomorphons elements of flats (24.3%), valleys (15.7%), slopes (13.4%), ridges (12.2%) and footslopes (11.3%). The landform characteristics are show in the schematic drawing in figure 7.

The association of these elements forms the contact between the geomorphologic domains of the *Middle Tocantins Depression and Alto Parnaiba Chapada* with rocks of the sedimentary basins.

Unit 11

This unit is divided into *three* major areas located in the southcentral part of the state and is characterized by the predominance of flats and slopes, 22.5% and 21.3%, respectively. In addition, there are valleys (13.3%), spurs (9.7%), ridges (9.1%), footslopes (8.4%), and hollows (8.3%). Furthermore, this unit is characterized by the presence of valleys and ridges with some features well represented by the ridges. The schematic drawing shows the landform characteristics of this unit (figure 7).

This unit is in the extreme south of the state, on metasedimentary rocks of the *Alto Tocantins-Parnaiba Plateau* and in the southeastern part, constituting the geomorphological unit *Natividade Sierra* with substrates of metasedimentary rocks and landforms marked by foldings.

Unit 12

The geomorphons elements in this unit are composed of flat areas (32.2%) and slopes (15.5%). Valleys (8%), foot slopes (6.9%), shoulders (6.7%) and hollows (6.5%) are also significant in this unit. The schematic drawing in figure 7 shows the landform characteristics. This unit presents the most significant hollow element when compared to the other units.

The unit covers a narrow strip area at the edge of the southeastern portion of the state. It is related to the geomorphological domains of the *Western Baiano Chapadão, Cliffs,* and *Mangabeiras Cliffs*, consisting of sedimentary rock substrates of the sedimentary basins.

Unit 13

This unit includes three major areas located in the central portion of the state, which are characterized by slopes (19.7%), valleys (16.9%), ridges (14%), flats (13.3%) and spurs (11.9%). Specifically, it is represented by slopes with narrow and elongated tops forming ridges and spurs. Moreover, these peaks are common elements at the top of the slope and hollow elements in the middle slope. The schematic drawing of the landforms of this unit is shown in figure 7.

The combination of these geomorphons elements is associated with a relief of relatively resistant sedimentary rocks and crystalline basement forming the geomorphological *Tocantins Plateau Dissected, Araguaia-Tocantins Plateau*, *Malhada Alta Sierra* and *Tocantins Depression*.

CONCLUSIONS

The development of geotechnology provides the procedures and techniques to assist in the analysis of landforms through modelling and interpretation of digital elevation models.

In this work, the core of the method is presented, which is the use of geomorphons, which represent a relief-invariant, orientation-invariant, and size-flexible and abstracted unit of relief. The relief is expressed in terms of the local ternary pattern that encapsulates the morphology of the surface around the point of interest.

The compartmentalization of the landforms occurred through the manual grouping of the main geomorphons elements, determining 13 landforms units.

The proposed identification of the landform elements, called geomorphons, proved to be a very effective technique for the determination of different landform compartments in the state of Tocantins since they correspond to geomorphologically-recognized units.

Thus, it can be observed that the geomorphons elements allowed the recognition of the large areas of the state with features marked by relief aspects such as low flat areas of the *Bananal* Island in the western region of the state and the predominance of reliefs of the plateau with flat tops and cliffs of *Jalapão* in the east.

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