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SCIENCE

Geodiversity assessment of the Xingu drainage basin

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Geodiversity is a recent concept that refers to the abiotic variety of nature. It is defined as the range of geological (rocks, minerals, fossils), geomorphological (landforms, processes) and soil features, including their assemblages, relationships, properties, interpretation and systems. In this work, a method of quantitative assessment of geodiversity was applied to the Xingu drainage basin (Amazônia – Brazil). The method is based on the quantification and integration of abiotic features represented on thematic maps at scales ranging from 1:250,000 to 1:2,500,000, overlaid by a 1:25,000 systematic grid. In order to calculate the final geodiversity index, five partial numerical indices representing the main components of geodiversity were drawn compiled: geology, geomorphology, soil, palaeontology and mineral occurrences. The resulting Geodiversity Index map is presented in the form of five isoline classes. The objective of this method is to present such a mapping technique as a tool for environmental planning, particularly for the identification and definition of priority areas for conservation.

Keywords: geodiversity; assessment; Amazonia; Xingu

1. Introduction

The evaluation and mapping of geodiversity are recent subjects, which have received significant contributions from amongst others, Kozłowski (2004), Benito-Calvo, Pérez-González, Magri, and Meza (2009), Serrano, Ruiz-Flaño, and Arroyo (2009), Hjort and Luoto (2010), Zwoliński (2010), Ruban (2010) and Pereira et al. (2012). This work follows the definition of the concept of geodiversity established by Sharples (1993) and later, consolidated by Gray (2004), which defines geodiversity as: ‘The natural range (diversity) of geological (rocks, minerals, fossils), geomorphological (landforms, processes) and soil features. It includes their assemblages, relationships, properties, interpretation and systems’. Geodiversity maps are now considered potentially useful for territorial management, particularly for protected areas.

These maps are products that integrate the wide range of elements that characterize the abiotic environment, namely: relief, rocks, soils, water and the occurrence of minerals and fossils.

The presented methodology was applied to the Xingu River basin, located in the Brazilian states of Pará and Mato Grosso (Figure 1). The Xingu River is approximately 2600 km long.
and is a southwest tributary of the Amazon River. The Xingu Basin covers a total area of 511,000 km². Around 60% (305,000 km²) of this area comprises 28 Indian territories and 18 conservation units – an area legally protected from deforestation (JUSBRASIL, 2009).

2. Methodology

The maps produced for the Xingu Basin were based on the methodology presented by Pereira et al. (2012). In this work, the authors produced a map for the state of Paraná (Southern Brazil) as a result of the calculation of several geodiversity indices over an overlay grid, which divided their area of study. Initially, available maps of relief, rocks, soils, mineral resources and fossils with scales ranging from 1:500,000 to 1:650,000 were used and partial geodiversity indices calculated by counting the number of occurrences of each element (e.g. the number of geological units, the number of geomorphological units, the amount of mineral resources in each square). Following this procedure, five partial numerical indices were obtained for: geological, geomorphological, pedological, palaeontological and mineral occurrences.

Finally, these indices were aggregated in order to obtain a geodiversity index score for each grid square. Thus, a Geodiversity Index map was produced using isolines to join squares with similar geodiversity values into five classes: very low, low, medium, high and very high.

Figure 1. Location of the Xingu drainage basin and protected areas. Source: IBGE, 2000.
The present method provides similar weight to the diverse components of geodiversity and avoids overrating any particular element, a common issue with many other evaluation methods. All the components – lithology, relief, hydrography, fossils, soils, and minerals – were represented in a holistic way, considering the quantification of the whole range of abiotic diversity.

This work uses a systematic cartographic grid with a 1:25,000 scale, generating 2462 grid squares, each with an area of approximately 13.8 × 13.8 km, in order to cover the whole Xingu drainage basin, whose area corresponds to a medium-sized country. Values were attributed to each square within the drainage basin, according to each of the themes described below.

3. Geological diversity

For this index, a 1:250,000 scale digital base geological map produced by Instituto Brasileiro de Geografia e Estatística (IBGE, 2000) was used. An automatic count of the different geological units occurring in each grid square proceeded. To accomplish this, the following operational procedures were performed:

- Each geological unit was given a numeric code, e.g. Alter do Chão Formation – code: 235.
- Multiple polygons of the same geological unit were ‘dissolved’ so that they would not be taken into consideration more than once; this may occur where there are two or more identical polygons within each grid square.
- the geological units were linked to the 1:25,000 systematic grid through a ‘union’ procedure
- the number of different geological units inside each square of the 1:25,000 grid were counted (Figure 2A).

After these procedures, the partial geological diversity index map was generated by transforming the systematic grid into a points file and then generating a continuous surface by interpolating the points using inverse distance weighting (IDW). The resulting raster was reclassified into five categories, from very low to very high (Figure 3A). IDW determines cell values using a linearly weighted combination of a set of sample points; the weight is a function of inverse distance.

4. Geomorphological diversity

This index took into consideration three sub-indices:

(1) Geomorphological units. The method quantifies the morphosculptural sub-units or tirth taxon (Santos et al., 2009). To quantify this sub-index, a 1:250,000 scale digital base geomorphological map (IBGE, 2000) was used. The counting procedure was the same as that described for Geological Diversity (Figure 2F).

(2) Structural contacts between morphostructural units corresponding to the first taxon (Santos et al., 2009). This method attributes one point for each boundary between the first taxon units. For squares where only one unit of this hierarchy occurs, it was attributed a value of zero (Figure 2G). The counting procedure was the same as for Geological Diversity.

(3) Hydrography. The official systematic maps of Amazon, containing the hydrographic network, were produced on various dates, by different working groups and using diverse inputs, generating different densities of information. For this reason, the 1:2,500,000 scale shapefile of Brazilian hydrography (ANA, 2010) was adopted, containing information about the main rivers of the drainage basin.
This shapefile was cut around the Xingu Basin area and the fluvial hierarchy was determined based on the method of Strahler (1957). The value attributed to each river was hierarchy/2, rounded up to the nearest unit (e.g. 5/2 = 2.5, therefore, the resulting score was 3). The values
were inserted manually into the hydrography attribute table. The value of the river with the greatest order assigned given to each square (Figure 2H).

The sum of the three previous sub-indices resulted in the geomorphological index attributed to each square (Figure 2E). The procedure to generate the partial geomorphological diversity map (Figure 3B) is the same as that described for Geological Diversity.

5. Pedological diversity

The same procedures adopted for Geological Diversity were used with the 1:1,000,000 scale Soils Survey vector file (IBGE, 2003) (Figure 2B). The pedological index values facilitate the tracing of the pedological diversity map (Figure 4A).

6. Mineral diversity

To quantify the number of mineral occurrences, the Geological Survey of Brazil basemap (CPRM, 2004, 2008) was used. As the data are composed of points, not polygons, the data were ‘intersected’
with the systematic grid. The score of one point was given for each type of mineral occurrence contained within a grid square (Figure 2C). These values permitted the tracing of mineral diversity (Figure 4B) using a procedure similar to that described for Geological Diversity.

7. Palaeontological diversity
The quantification of fossiliferous units considers the score of one point for each geological unit with fossils information from the geological map at a scale 1:250,000 within each square of the systematic grid (Figure 2D). The digital procedure was the same as in other themes based on vector polygon files, as described for Geological Diversity (Figure 5A).

8. Geodiversity
The final geodiversity value in each square of the systematic grid is the result of the sum of the partial indices (Figure 2I). The Geodiversity Map was generated from the calculated points using IDW.
(Figure 5B). IDW was chosen because is possible to control the significance of known points on the interpolated values. This method assumes that the variable being mapped decreases in influence with distance from its sampled location, unlike other methods which can produce a prolonged influence of a sampling point as a function of the distances of the samples. The location of protected areas was also inserted in the map, in order to demonstrate the spatial relationship between the indices of geodiversity and the areas currently protected by Brazilian Law (see Main Map).

9. Conclusion

The growing acceptance and importance of geodiversity in territorial management, particularly concerning the preservation of nature, will soon demand maps that express this concept. The described procedure optimizes the geodiversity mapping methodology proposed by Pereira et al. (2012). This optimization is obtained through the use of GIS, allowing its application to extensive areas, such as the Xingu River drainage basin. It represents a step forward in the evolution of the quantitative assessment of abiotic environments.
It is important to highlight, that in order to create the Geodiversity Map, cartographic products already in existence are used, such as geological, geomorphological, pedological and mineral resources maps.

The index of geodiversity ranged from 4 to 28. The ‘hot spot’ of geodiversity occurs at the boundary between the pre-Cambrian Complex of Xingu and the Amazon Sedimentary Basin, near the area called Volta Grande do Xingu, where there are many different types of rocks, soils and landforms, and mineral occurrences. The second area with high geodiversity occurs near the city of São Félix do Xingu, where outcrops of older rocks, various types of relief and plentiful mineral resources in a rugged region. There is also an area with high geodiversity in the south of the basin, due to the variety of rock types and forms and the presence of sites with high fossiliferous potential (see Main Map).

In the specific case of the Xingu River Basin it is possible to realize that in areas of higher geodiversity there is no kind of legal protection (see Main Map). This fact demonstrates that the criteria used in the definition of protected areas did not take into account issues of abiotic nature, and the hot spot of geodiversity occurs exactly in the area where the Belo Monte Hydroelectric Power Plant, which will be the third largest in the world, is being constructed.

The same map also supports the increasing interest in decisions that respect territorial management, particularly with regard to the preservation of nature.

Software
Map design was performed using Esri ArcGIS 9.3 software.

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