QUANTIFICATION OF A NEW WATER DIVERSITY INDEX FOR LARGE AREAS USING GIS. EXAMPLES IN PARANÁ STATE, XINGU RIVER BASIN (BRAZIL) AND PORTUGAL

P. Pereira (1), *D. Pereira* (1), *L. Santos* (2), *J. Silva* (3)

(1) Instituto de Ciências da Terra, Polo da Universidade do Minho, Campus de Gualtar, 4710-057 Braga, Portugal. paolo@dct.uminho.pt, insuad@dct.uminho.pt
(2) Departamento de Geografia, Universidade Federal do Paraná, Av. Cor. Francisco dos Santos, S/N, Jardim das Américas, CEP 81531-980, Curitiba, Brasil. santos.ufpr@gmail.com
(3) IBGE - Instituto Brasileiro de Geografia e Estatística, Rua de Nazaré e Odyllo, 49, CEP 65010-410 São Luís, Maranhão, Brasil. julianadepaula@yahoo.com

Resumen (Cuantificación de un nuevo index de diversidad hídrica para grandes áreas con SIG: ejemplos en lo estado del Paraná, en la cuenca del rio Xingú (Brasil) y en Portugal): *Se presenta un método para la evaluación cuantitativa de la diversidad de recursos hídricos en grandes áreas, con los ejemplos del estado de Paraná (Brasil), de la Cuenca del rio Xingú (Brasil) y de Portugal continental. En la mayoría de las propuestas metodológicas para evaluación de la geodiversidad, la diversidad hidrológica respecta a las características de la hidrografía, en relación con la diversidad de geoformas fluviales. Este trabajo pretende contribuir al inclusión de recursos hídricos como un elemento significativo en metodologías de evaluación de la geodiversidad, incluyendo tanto las aguas superficiales y aguas subterráneas. El uso de procedimientos de SIG demuestra que estas técnicas pueden ser utilizados para acelerar el cálculo de los índices de diversidad y su representación cartográfica.*

Palabras clave: Index de diversidad hídrica, evaluación cuantitativa, recursos hídricos, Brasil, Portugal.
Key words*: Water diversity index, quantitative assessment, water resources, Brazil, Portugal.*

INTRODUCTION

Geodiversity is defined as the natural range (diversity) of geological (rocks, minerals, fossils), geomorphological (landforms, topography, physical processes), soil and hydrological features. It includes their assemblages, structures, systems and contributions to landscape (Gray, 2013).

Water features are therefore elements of geodiversity, being a very important agent in geological and biological processes and evolution. Their quantitative assessment has a special importance in the scope of the hydrological diversity and some special hydrological features may be considered as geological heritage (Simić, 2011; Cruz et al., 2013).

Besides, water is a vital resource for human activities and survival. It must be understood as an environmental and social asset, an economical resource and a matter of extreme importance for all societies. Water resources management is a technical subject and also a political topic since water needs can lead to different ambitions by different factions evolving priority decisions and conflicts.

The quantitative assessments of water resources and of their diversity along a large territory constitute the basis for the knowledge of regional issues concerning water needs, flood and droughts events and even engineering solutions for water resources management.

To be accepted as a useful tool, diversity must be assessed according to objective methodologies in order to be used for nature conservation and land-use planning, as biodiversity currently is. Common geological, geomorphological, soil or hydrographical maps are important in qualitative, but not in quantitative diversity assessment. In addition, as technical documents, they are difficult to read for non-specialists, thus limiting their use in routine planning (Pereira et al., 2013).

In most methodological proposals to geodiversity assessment, hydrological diversity is mainly connected with hydrography features, in relation with fluvial landforms diversity. Thus, one should debate which water features to include in geodiversity assessment procedures, enhancing both surface water resources more connected with geomorphological diversity and ground water as an essential component of water resources (Winter et al., 1998).

The hydrological diversity assessment in three large areas is presented, with the methods and results of the cases of Paraná State (Brazil), Xingu River Basin (Brazil) and Portugal mainland.
.

METHODS AND STUDY AREAS

The hydrological diversity was assessed in the scope of a broader geodiversity assessment. The work followed a methodology based on the counting of different occurrences by territory portions (cells), using cartographical data and GIS procedures analysis. It intends to express, in the most balanced way possible, all geodiversity elements without emphasizing any particular one, as was noted to occur in previous studies (Carcavilla et al., 2007; Serrano and Ruiz-Flaño 2007; Benito-Calvo et al., 2009; Hjort and Luoto, 2010).

The method was initially tested on the Paraná State, located in southern Brazil, with an area of 199,570 km^2 (Pereira et al., 2013). In this approach, the geodiversity index results from the sum of the following five partial indexes: i) lithological; ii) geomorphological; iii) paleontological; iv) pedological; v) mineral occurrences.

The procedure consists in the overlay of a grid over geological (MINEROPAR, 2006a), geomorphological (MINEROPAR, 2006b; Santos et al., 2009), paleontological (MINEROPAR, 2006a) and soils maps (Bhering and Santos, 2008), with scales ranging from 1/650,000 to 1/500,000. Besides these, other maps provided information regarding occurrences of precious stones and metals, industrial metals and minerals, geological energy sources such as coal, oil, gas and uranium, and sources of mineral waters and springs. A cell-size of 25x25 km was defined resulting in 371-cell grid covering all the state area.

Water features were considered under the form of the Hydrographical sub-index, which is included in the geomorphological index, taking into account the influence of hydrological features on geomorphology. The Hydrographical sub-index is based on the assessment of the 1/650,000 scale geomorphological units map (MINEROPAR 2006b) using Strahler's system of stream ordering (Strahler, 1952, 1957).

According to this system, the lowest hierarchy level is assigned to minor rivers represented on the map, while the highest value of 5 is conferred on major rivers, such as the Paraná River on the Brazil-Paraguay border, as well as lakes and coastal areas. To large tributaries like Paranapanema and Iguaçu rivers intermediate values were assigned. The value of the Hydrographical sub-index is calculated as half of the maximum hierarchical level of the rivers occurring in each square, rounded up to the nearest unit (Fig. 1). Accordingly, a score of 3 (5/2 = 2.5 ≅ 3) is given to squares containing major rivers, lakes, and coastal areas, of 2 (4/2 = 2; 3/2 = 1.5 ≅ 2) to squares containing mid-sized rivers, and of 1 (2/2 = 1; 1/½ = 0.5 ≅ 1) to squares with minor rivers. A score of 0 is assigned to squares, in which no hydrological elements are represented.

Few changes to this method were made for the calculation of geodiversity indexes and the production of the Geodiversity Map of the Xingu Basin, Amazon, Brazil, with an area of about 511,000 km^2 (Silva et al., 2013, 2014). The Xingu River is approximately 2600 km long and is a southwest tributary of the Amazon River. Around 60% (305,000 km^2) of this area comprises 28 Indian territories and 18 conservation units – an area legally protected from deforestation. The analysis was supported by geological and geomorphological maps at 1/250,000 scale and by a soil map at 1/1,000,000 scale.

The most relevant upgrade respect to the use of ESRI ArcGIS© software for counting the geodiversity occurrences, the indexes calculation and the automatically generated polygon map, drawn over a 2462-cell grid with a cell-size of 13.8 x 13.8 km.

The values for river hierarchy were automatically inserted into the hydrography attribute table with the value of the river with the greatest order assigned given to each square (Fig. 2).

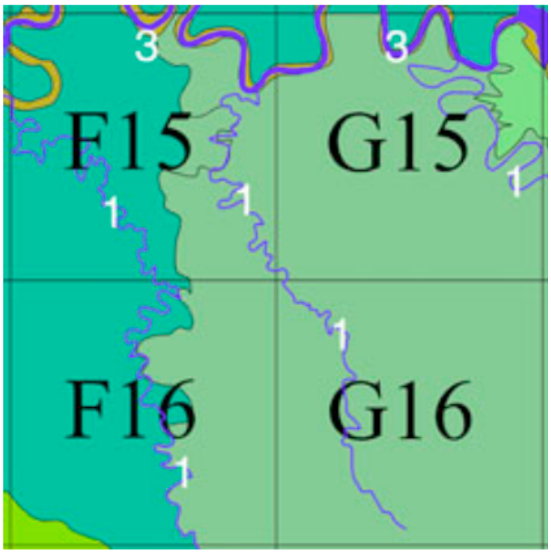

Fig. 1: Example of the Hydrographical sub-index assessment in a 25 X 25 km cell-size grid overlaid on the geomorphological units map of Paraná State (Pereira et al., 2013): squares F15 and G15 score 2 points; F16 and G16 score 1 point (see text for further information).

The same methodological approach is being applied in Portugal mainland that covers an area of 89,000 km^2 with modifications being introduced, namely: introduction of a rectangular shaped (16x10 km) 612-cell grid in order to obtain a relation between the geodiversity index and the most popular mapping coverage of Portugal mainland, at 1/25,000 scale; because partial indexes may have very different ranges, these were normalized to a maximum of 1 point, in order to attribute the same weight to all sub-indexes in the final value regarding geodiversity; Geomorphological Index calculation is now based only in the diversity of geomorphological units, with the subtraction of the hydrographical sub-index; Hydrographical features are therefore included in the new Hydrological Index, which results from the analysis of rainfall and runoff data, drainage density and stream ordering, aquifer productivity and natural and artificial water reservoir occurrences (Fig. 3).

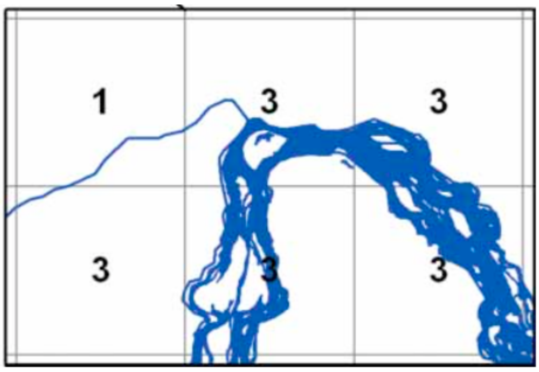

Fig. 2: Example of the Hydrographical sub-index assessment in a 13.8 X 13.8 km cell-size grid overlaid on the hydrography map of Xingu River basin (Silva et al. 2013, 2014): the value assigned to each cell was river hierarchy/2, rounded up to the upwards unit (e.g. 5/2 = 2.5, therefore, the resulting score was 3).

Like before, this assessment is based in a set of pre-existent official maps (rainfall, runoff, and aquifer systems productivity). It also considers operations over hydrography maps and the Digital Elevation Model (DEM) to determine drainage density, water coverage and stream ordering.

RESULTS AND DISCUSSION

The methodology for geodiversity quantification and mapping is based on cartographic data concerning geology, geomorphology, palaeontology, soils, water, and mineral and energy sources occurrences. Therefore, scale selection, legend level, and grid-size are essential aspects, with each of the geodiversity elements being assessed to avoid overrating any particular component, such as lithology or relief. In the three cases, various grid sizes were tested in order to obtain the best balance between results discrimination and the number of cells. The cartographic scales, legend levels, and grid size chosen revealed to be appropriate, providing a clear distinction of values for the various indices.

The Geodiversity Index score of each grid square is the sum of all the previously outlined partial indices. A Geodiversity Index map (and also partial indices maps) can therefore be produced through contour lines that join squares sharing the same geodiversity values.

Specifically regarding the hydrological component, it was considered under the form of the Hydrographical sub-index in Paraná State and Xingu River basin analysis. In these cases, that component only considered the stream ordering analysis, being included in the Geomorphological index, taking into account the influence of hydrological features on geomorphology. Therefore, the Geomorphological Index values range widely, wherein the highest values are near large rivers due to the fact that the Hydrographical sub-index was based on fluvial hierarchy.

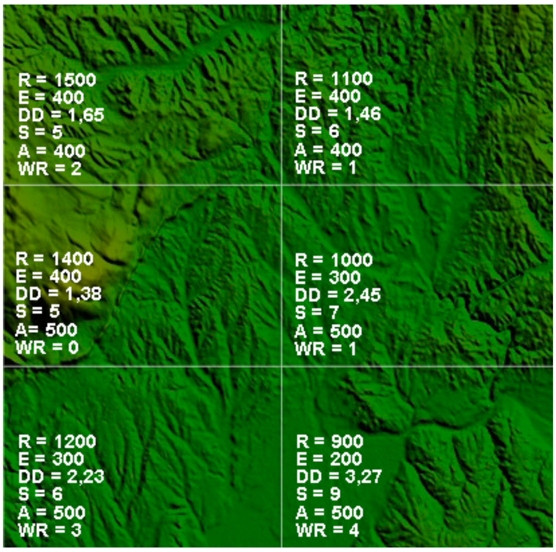

Fig. 3: Example of the Hydrological Index assessment in a 16 X 10 km cell-size grid overlaid on the Digital Elevation Model (DEM) of Portugal mainland: R - rainfall (annual, in mm); E - runoff (annual, in mm); DD - drainage density (km per km^2); S - stream ordering (highest hierarchy value, according to Strahler method); A - aquifer productivity (m^3/ [day-km2]); W - water surfaces (larger than 10,000 m^2). The values are subsequently interpolated and normalized to a maximum value of 1.0, according to the maximum values for each hydrological feature under analysis, with the Hydrological Index being the average of these normalized values.

Nevertheless, the use of GIS procedures in the Xingu River basin analysis demonstrates that these techniques can be used to speed-up the calculation of the partial indices and its cartographic representation. Through the use of these techniques, geodiversity maps can then be produced for large territories if solid and official mapping is available.

The application of the methodology to Portugal mainland highlights the identical weight of the partial indexes for the calculation of the geodiversity index. Besides, in this new approach, the geodiversity index results from the sum of six partial indexes (lithological, geomorphological, paleontological, pedological, mineral occurrences, and hydrological) and theoretically each of the 612 cells may achieve 6 points of maximum value.

These new proposal aims to contribute to the inclusion of hydrological features as a significant item in geodiversity assessment methodologies rather than be only considered in geomorphological diversity. Consequently, the geodiversity assessment becomes more complete, including both surface water and ground water, in a water resources perspective.

The hydrological diversity in Portugal reveals the high geological diversity, in general, and mostly the climatic disparities within the territory. Even being a small country, Portugal presents big differences in rainfall values, with the north and coastal areas more influenced by the Atlantic atmospheric circulation.

The comparison of results from the presented cases reflects the need to complete the assessment with more hydrographical features in Portugal and more hydrological data in the Brazilian territories. The Hydrographical sub-index (within the Geomorphological index) was not used, revealing particularly difficult to quantify attending to the fact of the larger Portuguese basins constitute the downstream sectors of the Iberian basins.

Hydrological diversity maps can combine information that is usually scattered across multiple sources allowing an easy understanding by non-earth science experts. Such tools can then be used in land-use planning, nature conservation, natural hazards and water resources management.

Acknowledgements: The Portuguese authors express their gratitude for the financial support given by the FCT (Fundação para a Ciência e a Tecnologia) to the Institute of Earth Sciences (Pole of the University of Minho), which partially supports this research. The Brazilian authors express their gratitude for the financial support given by the CNPq (Conselho Nacional de Desenvolvimento Científico e Tecnológico) and CAPES (Cordenação de Aperfeiçoamento de Pessoal de Nível Superior).

References

Benito-Calvo A., Pérez-González A., Magri O., Meza P. (2009). Assessing regional geodiversity: the Iberian Peninsula. Earth Surface Processes and Landforms, 34(10), 1433-1445.

Bhering S., Santos H. (Eds.) (2008). Mapa de Solos do Estado do Paraná, Legenda atualizada. Instituto Agronómico do Paraná / Embrapa, Rio de Janeiro. 74 pp.

Carcavilla L., López J., Durán J. (2007). Patrimonio geológico y geodiversidad: investigación, conservación, gestión y relación con los espacios naturales protegidos. Cuadernos del Museo Geominero 7, IGME, Madrid. 360 pp.

Cruz R., Goy J. & Zazo C. (2013). Geodiversity and Hydrological Patrimony in High Mountain Areas. Gredos Range: Béjar and El Barco Massifs, Spain. Inventory and Cataloguing. In: Management of Water Resources in Protected Areas (H. Farfán, J. Corvea, I. Bustamante and J. LaMoreaux, Eds.). Springer, Environmental Earth Science Series, 329-338.

Gray M. (2013). Geodiversity: Valuing and Conserving Abiotic Nature, Wiley, 2nd Ed., 508 pp.

Hjort J., Luoto M. (2010). Geodiversity of high-latitude landscapes in northern Finland. Geomorphology, 115(1-2), 109-116.

MINEROPAR - Minerais do Paraná (2006a) Atlas geológico do Paraná, escala 1:250.000. Modelos reduzidos a 1:500.000. Governo do Paraná, Secretaria de Estado da Indústria, Comércio e Turismo, Curitiba.

MINEROPAR - Minerais do Paraná (2006b) Cartas Geomorfológicas do Estado do Paraná, escala 1:250.000. Modelos reduzidos a 1:500.000. Governo do Paraná, Secretaria de Estado da Indústria, Comércio e Turismo, Curitiba.

Pereira D.I., Pereira P., Brilha J., Santos L. (2013) Geodiversity assessment of Parana State (Brazil): an innovative approach. Environmental Management, 52, 541-522.

Santos L.C., Oka-Fiori C., Canali N., Fiori A., Silveira C., Silva J. (2009). Morphostructural Mapping of Paraná State, Brazil. Journal of Maps, v.2009, 170-178.

Serrano E., Ruiz-Flaño P. (2007). Geodiversity: a theoretical and applied concept. Geographica Helvetica, 62(3), 140-147.

Strahler A.N. (1952). Hypsometric (area-altitude) analysis of erosional topography. Geological Society of America Bulletin, 63(11), 1117-1142.

Strahler A.N. (1957). Quantitative analysis of watershed geomorphology. Transactions of the American Geophysical Union, 8(6), 913-920.

Silva J.P., Pereira D.I., Aguiar A.M., Rodrigues C. (2013). Geodiversity assessment of the Xingu drainage basin. Journal of Maps, 9, 1-9.

Silva J.P., Rodrigues C., Pereira D.I. (2014). Mapping and Analysis of Geodiversity Indices in the Xingu River Basin, Amazonia, Brazil. Geoheritage, DOI 10.10007/s12371-014-0134-8

Simić S. (2011). Hydrological heritage within protection of geodiversity in Serbia - legislation history. Journal of the Geographical Institute Jovan Cvicić, 61(3), 17-32.

Winter T., Harvey J., Franke O., Alley W. (1998). Ground Water and Surface Water: A Single Resource. U.S. Geological Survey Circular 1139, 79 pp.

Granada 2015

XIV Reunión Nacional de Cuaternario, Granada

30 de Junio, 1 y 2 de Julio 2015

Una visión global del Cuaternario

El hombre como condicionante de procesos geológicos

Patrocinio científico e institucional:

MINISTERIO DE ECONOMÍA Y COMPETITIVIDAD

Instituto Geológico y Minero de España

AEQUA

BETA
Radiocarbon Dating
Consistent Accuracy
Delivered On-Time
Beta Analytic Ltd.

JUNTA DE ANDALUCIA
Patronato de la Alhambra y Generalife
CONSEJERÍA DE EDUCACIÓN, CULTURA Y DEPORTE

MINISTERIO DE ECONOMÍA Y COMPETITIVIDAD

CSIC
CONSEJO SUPERIOR DE INVESTIGACIONES CIENTÍFICAS

Organización:

Universidad de Granada
Dpto. Geodinámica

ANÁLISIS DEL RELIEVE Y PROCESOS ACTIVOS

J. P. Galve, J. M. Azañón, J. V. Pérez Peña y P. Ruano (Eds.)

J. P. Galve, J. M. Azañón, J. V. Pérez Peña y P. Ruano (Eds.)

Foto portada: Vista aérea del borde occidental de Sierra Nevada desde la parte norte de la Cuenca de Granada. En primer plano se aprecia el abanico aluvial de la Formación Alhambra, sobre el que se asientan los Palacios Nazaríes del mismo nombre, disectado por los ríos Darro y Genil. Detrás en un segundo plano y hacía el SE se distinguen los relieves de media montaña en los que aflora el Complejo Alpujárride y los relieves nevados de alta montaña en los que aflora el Complejo estructuralmente más bajo de las Zonas Internas de la Cordillera Bética, el Complejo Nevado-Filabride. Fuente: Aviofoto.

Diseño portada: José Vicente Pérez Peña, Patricia Ruano y Jorge Pedro Galve

Depósito legal E-book formato pdf: GR-876-2015

ISBN E-book formato pdf: 978-84-606-9417-5

Los trabajos contenidos en el presente volumen deberán citarse de la siguiente manera:
Cearreta, A. (2015). El "Anthropocene Working Group" y la definición geológica del Antropoceno. En: Una visión global del Cuaternario. El hombre como condicionante de procesos geológicos (J. P. Galve, J. M. Azañón, J. V. Pérez Peña y P. Ruano, Eds.), pp. 248-251. XIV Reunión Nacional de Cuaternario, Granada (España).

Una visión global del Cuaternario. El hombre como condicionante de procesos geológicos

Jorge Pedro Galve, José Miguel Azañón, José Vicente Pérez Peña y Patricia Ruano (editores)

XIV Reunión Nacional de Cuaternario. Granada, 2015

Coordinación:

José Miguel Azañón Hernández. Dpto. Geodinámica (UGR)

José Vicente Pérez Peña. Dpto. Geodinámica (UGR)

Jorge Pedro Galve Arnedo. Dpto. Geodinámica (UGR)

Comité organizador:

Pedro Alfaro (UA), María Begoña Bautista Dávila (USAL), Patricia Brañas (GRXWorkshop), Julia Castro (UA), Francisca Fernández (UGR), Francisco Juan García-Tortosa (UJAEN), Flavio Giaconia (UGR), Pedro Huerta (USAL), Iván Martín Rojas (UJAEN), Rosa M. Mateos (IGME), Davide Notti (UGR), Francisco J. Roldán (Instituto Geológico y Minero), Patricia Ruano (UGR, IACT-CSIC), Juan Carlos Rubio (IGME), Pablo Silva (USAL)

Comité Científico:

José Miguel Azañón (UGR), Antonio Azor (UGR), Javier Baena (UAM), Teresa Bardají (UAH), Alfonso Benito (CENIEH), Guillermo Booth-Rea (UGR), Pilar Carmona (UV), Rosa Carrasco (UCLM), Alejandro Cearreta (UPV), Fernando Díaz del Olmo (US), Andrés Díez (IGME), Jorge P. Galve (UGR), Francisco Javier Gracia (UCA), Inma Guerrero (US), Francisco Gutiérrez-Santolalla (UNIZAR), Pedro Huertas (USAL), Gonzalo Jiménez (UGR), Jesús Francisco Jordá-Pardo (UNED), Angel Martín-Serrano (IGME), Rosa M. Mateos (IGME), Ana Moreno (IPE-CSIC), José Vicente Pérez-Peña (UGR), Francisco Pérez-Torrado (ULPGC), Miguel Ángel Rodríguez- Pascua (IGME), Joaquín Rodríguez-Vidal (UHU), Francisco J. Roldán (IGME), Antonio Rosas (MNCN-CSIC), Patricia Ruano (UGR), Pablo Silva (USAL), Cesar Viseras (UGR).

Organización:

Departamento de Geodinámica. Universidad de Granada
Grupo de Análisis del Relieve y Procesos Activos

Patrocinio científico e institucional:

AEQUA

Patronato de la Alhambra y Generalife

Instituto Geológico y Minero de España

CSIC

Beta Analytic Ltd.