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Geodiversity assessment in a rural landscape: Tiermes-Caracena area (Soria, Spain)

Valutazione della geodiversità del paesaggio rurale: l'area di Tiermes-Caracena (Soria, Spagna)

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ABSTRACT – In this paper an index is developed to assess geodiversity, which can be applied to territories with different characteristics. The first step is to make a geomorphological map and to delimit the morphological units where the geodiversity index is to be calculated. The relationship between the physical elements, the surface and roughness are established by means of the index. The physical elements, taken from the geomorphological, geological and soils map, field work and the bibliography, are geological structures, morphostructures, erosional and accumulation features, morphogenetic systems, erosional processes, micro-landforms, soils and hydrological elements. Roughness is calculated from the slope map. Five types of geodiversity enable us to classify the units. This method is applied to a rural landscape of southern Duero basin (Soria Province, Spain) and a map of geodiversity is made.

KEY WORDS: Geodiversity assessment; Geoconservation; Geomorphology; Tiermes; Spain.

RIASSUNTO – In questo articolo viene presentata la metodologia utilizzata per ottenere un indice di geodiversità applicabile a territori con differenti caratteristiche. La prima fase consiste nella realizzazione di un carta geomorfologica e nella delimitazione delle unità moorfologiche per le quali viene calcolato l'indice di geodiversità, che mette in relazione gli elementi fisici, la superificie e la rugosità dell'unità. Gli elementi fisici, desunti dalle carte geomorfologiche, geologiche, pedologiche, da rilevamenti di campagna e da indagine bibliografiche, sono: strutture geologiche, morfostrutture, forme di erosione e di accumulo, sistemi morfogenetici, processi attivi, microforme, suoli ed elementi idrologici. La rugosità viene calcolata a partire dalla carta del pendio. Sono stati individuati cinque diversi gradi di geodiversità che consentono di classificare le diverse unità morfologiche. Il metodo qui presentato è stato applicato al paesaggio rurale del settore meridionale del bacino del Duero (Provincia di Soria, Spagna) ed è stata realizzata una carta delle geoiverità.

PAOLE CHIAVE: Valutazione della geodiversità; Geoconservazione; Geomorfologia; Tiernmes; Spagna.

1. – INTRODUCTION

Owing to its recent invention the term geodiversity is found in few references but within them it has a double viewpoint - theoretical and applied. From the theoretical point of view the term geodiversity began as a synonym of "abiotic diversity", to differentiate it from biological diversity or biodiversity (DUFF, 1994). The first definitions of the term identify geodiversity with "geological diversity", and it is still used frequently at the present-day (DIXON, 1996; EBERHARD, 1997; JOHANSSON, 2000; NIETO, 2001). Later the concept gained a wider meaning and recently it has been defined by GRAY (2004) as *"the natural range (diversity) of geological (rocks, minerals, fossils), geomorphological (landform, processes) and soil features. It includes their assemblages, relationships, properties, interpretations and systems"*. KOZLOWSKI (2004) widened the concept to include the effect of human activity on geodiversity at the same level as natural processes. In GRAY's (2004) and PIACENTE's (2005) works it is possible to find wider definitions of geodiversity.

As it is linked to other very recent concepts such as geoconservation and geomorphosites, the applied aspect of geodiversity has been evident from the beginning. All authors are in agreement on the need to safeguard geodiversity, so it has become a decision tool for planning and management, and also for education. KOZLOWSKI (2004) gives good reasons for its conservation in an important paper concerned with the development and increase of biodiversity. For SERRANO (2002), geodiversity and biodiversity are the constituents

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of Natural Diversity, and are both necessary elements in the territorial assessment of Natural Protected Areas. By the same token, geodiversity is the main aspect and aim of geoconservation (Gray, 2004). Undoubtedly its importance will increase in the future due to its practical usefulness and also because of its ease of comprehension for technicians and territory managers. This resource makes it easier to use and relate different scientific disciplines (geography, geology, geomorphology, pedology, hydrology or topography).

The effectiveness of its incorporation into territory management depends on the availability of useful methods to estimate geodiversity. Theoretical thinking has not been accompanied by a methodological effort to establish geodiversity assessment methods. There has recently been a great development of assessment methods for geomorphosites (Panizza, 1992; Panizza, 2001; Panizza & Piacente, 1993; Serrano & González-Trueba, 2005), but very little has been done for geodiversity assessment (Serrano & Ruiz-Flaño, 2007). Gray (2004), for example, suggests the possibility of using spatial geodiversity measurements and geoindicators but he does not indicate how to do so. Kozlowski (2004) has applied a qualitative scale of five sorts of geodiversity in Poland at a regional level and proposed its application to different states of the European Union.

2. – OBJECTIVES AND LOCATION OF STUDY SITE

The aim of this work is to develop a method to estimate, as objectively as possible, the geodiversity of a territory, and to quantify the geodiversity of different units to permit comparison both between units of a territory and between different geographical areas. Geodiversity is assessed by land units and work is applied on a local scale, in this case to a rural landscape of the southern area of the region of Castile and Leon to provide a geodiversity map that will be of use as a tool for planning and management.

The study area is located in the foothills of the Spanish Central System, on the south side of the Duero basin. The Tiermes-Caracena area is a marginal territory defined by heavy depopulation, an ageing population and land use abandonment without a functional replacement by other land uses (tourism, industry, and so on). In the study area there are 24 villages containing 700 inhabitants (population density of 2,3 inhab/km^2). The area has an important cultural heritage (Roman city of Tiermes, Medieval villages and castles; Romanesque churches, Islamic remains) together with the natural value of the landscape. It is a rural landscape characterised by the alternation of broad valleys and highlands crossed by fluvial gorges (fig. 1).

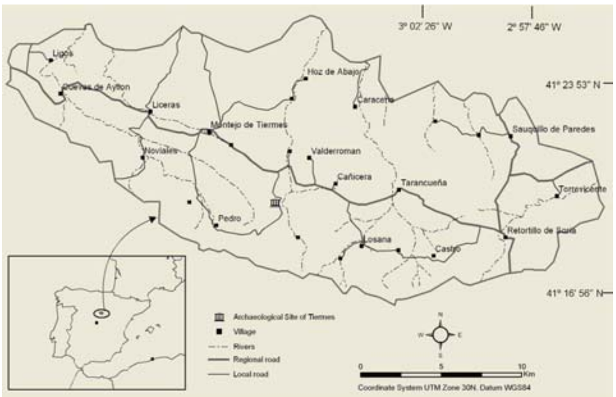

Fig. 1 – Location of Tiermes-Caracena area.
– *Inquadramento dell'area di Tiermes-Caracena.*

3. – METHODOLOGY

The procedure, used to establish the degree of geodiversity, is based on delimitation by geomorphological units and an inventory of the physical elements of each unit by means of the following:

- Analysis of abiotic elements: Study of geological, geomorphological, hydrological and pedological elements of the study area and drawing up a detailed geomorphological map.
- Establishment of units: The geomorphological units are the basis for the assessment of geodiversity and are delimited from the geomorphological map, aerial photography and field work. An inventory of the main physical characteristics of the units is made and summarised on cards (tab. 1).
- Assessment of units: an index which relates the variety of physical elements with roughness and surface of the units is created by assessing geodiversity. We began from the assumption that if there are more elements, geodiversity is greater, and the greater the roughness the greater will also be the micro and topo-climate complexity. Thus, the elements and roughness affect the increase in geodiversity. Accordingly, the following formula is applied:

$Gd = Eg R / \ln S$

Gd = Geodiversity index.

Eg = Number of different physical elements (geological, geomorphologic, hydrological and pedological) of the units;

R = Coefficient of roughness of the unit;

S = Surface area of the unit (km^2).

Tab. 1 – *Example of unit card for inventory of abiotic elements.*
– Esempio di scheda per l'inventario degli elementi abiotici.

Name: **Liceras-Retortillo Depression**	Coordenates: 41º 18´N 3º 7´ W		Altitude: Max.:1250
Number: 1.a	Surface: 73 km^2		Roughness: 1.2
ELEMENTS			
Lithology		- Conglomerate - mudstone - Marls	- Sandstone - Limestone - Dolomites
Geological structures		- Monocline - Faults with relief representativeness - Synclines	
Morphostructures		- Monocline ridges: backs, frontal scarp on Jurassic limestone, frontal scarp on Triassic conglomerates and sandstones - Orthocline depression	
Morphogenetic system		**ACTIVES**	**RELICTS**
		- Fluvial - Slopes - Weathering.	- Slopes - Fluvial - Weathering
Macro and meso landforms	Erosional landforms	- Rills, badlands - Landslides - Escarpements	- V-shaped valleys - Flat bottom valleys -Torrential Downcutting - Palaeovalleys
	Acummulation landforms	- Debris talus - Rock fall acummulations	- Fluvial terraces - Holocene infill - Glacis - Aluvial fans
	Anthropic landforms	--	--
Micro-landforms		--	--
Present-day processes	- Soil erosion and Badlands - Rock fall - Torrential streams - Landslide		
Represented Ages	-Triassic -Jurassic - Pleistocene - Holocene		
Hydrographical elements	- Rivers - Sinkhole - Torrents		
Soils	- Inceptisol - Entisol		

The parameter Eg is calculated from a recount of physical elements such as lithology, geological structures, geomorphology, morphostructures, erosional landforms and the presence of micro-landforms of interest. This data was obtained from the geomorphological, geological and soils maps (tab. 2). Only the different elements are counted and any repetitions are not taken into account. In the same way, only the processes that are not included in any landform are considered. Finally, the presence of hydrological and pedological elements are also included.

The topography and micro and topo-climate variations are represented by the roughness coefficient. Its incorporation is supported by the important role of both parameters on the energy flows (exposure to sunlight, humidity) and material flows (water, sediments on the slopes), and, in consequence, on the diversity and distribution of landforms and processes. It is an integrative parameter introduced to take account of the smaller variations and the complex relations between the elements and processes of the abiotic natural system. The roughness value is established from the dominant slopes in each unit. We have made a map of slopes using five intervals. The roughness coefficient of each unit corresponds to the dominant interval in the unit, according to the following scale.

roughness values	1	2	3	4	5
Slopes º	0-5	6-15	16-25	26-50	>50

If there are two dominant slope intervals very different to the other groups, a roughness value proportional to the surface area occupied by each interval is allotted.

Once the algorithm is applied the geodiversity of the unit is obtained. The following thresholds have been established:

Geodiversity	Very Low	Low	Medium	High	Very high
Values	<15	15-25	25-35	35-45	>45

4. – THE GEODIVERSITY IN TIERMES-CARACENA AREA: RESULTS

The Tiermes-Caracena area is characterised by folded relief formed by conglomerates, sandstones and clay of the Triassic Age, limestones, sandstones and marbles of the Jurassic and Cretaceous Ages, and conglomerates and sandstones of the Miocene Age. The area has extended anticline folds, where the Triassic rocks outcrop, and smaller folds affecting the Jurassic and Cretaceous cover.

The structural organization has formed a structural relief to the south characterised by the existence of "combes" next to the Sierra de Pela, with mixed ortocline valleys and monocline ridges. To the north a wide planation surface forms the extended highlands with fluvial palaeovalleys and karst features (Birot & Solé, 1954; García de la Vega, 2001; Rodríguez & Pérez, 2005). The highlands are divided by fluvial gorges, incised to 50-100 metres, which drain into the structural valleys and "combes". In the wider valleys shaped on soft rocks, two families of glacis and terraces have been formed (fig. 2).

In the study site 14 geomorphological units have been defined with different sizes and properties (figure 3 and table 3). Compared with the wide planation surface, with almost 200 km^2 of surface, there are units, like Pozo Moreno Gorge, of 1 km^2 of surface. This surface area has been deemed the minimum size for a unit in our scale of work. Seven units are fluvial valleys and several of them, Caracena and Talegones Gorges for example, are sharply incised on highlands. In these units the roughness reaches values as much as or even higher than 3. The Sierra de Pela has the steepest slopes, with a roughness coefficient value of 3.3. The least correspond, logically, to the planation surface and the ortocline valleys, and in second place the valleys formed in the pericline fold, which have a roughness coefficient value of 1. The other fluvial valleys and gorges have intermediate values.

The number of different elements hardly varies between units. The minimum values are located in the valleys, with values between 8 in the Madruédano Valley and 18 in the Talegones Gorge. The other units have values of between 20 and 42. The maximum values have been observed in the Liceras Retortillo depression (42) and in the Caracenas Gorge (30).

Figure 4 and table 3 show the geodiversity values calculated for the Tiermes-Caracena area. In general terms, geodiversity is low. In 75% of the surface (three units) geodiversity is very low due to the low values of slopes and wide surfaces. Five units (10,4% of the surface) have low values related to medium roughness and lesser surfaces.

Medium values are found in four units (9,7% of the surface). They are related to the high roughness of fluvial valleys and the range Sierra de Pela. Only one unit has a high value, the Caracena Gorge, where the diversity of constituent elements and roughness is higher. Only in one unit are very high values reached, which is more due to the small surface (hardly 0,3% of the study area) than by his abiotic constituents.

Tab. 2 – *Elements used to calculate the geodiversity index.*
– Elementi utilizzati per calcolare l'indice di geodiversità.

Geology	Lithology	Structure	
Geomorphology	Morphostrucures	Morphogenetic systems	Processes
Hydrology	Erosional landforms	Accumulation landforms	Micro-landforms
Soils	Water states	Hydrological elements	
	Orders	Sub-orders	

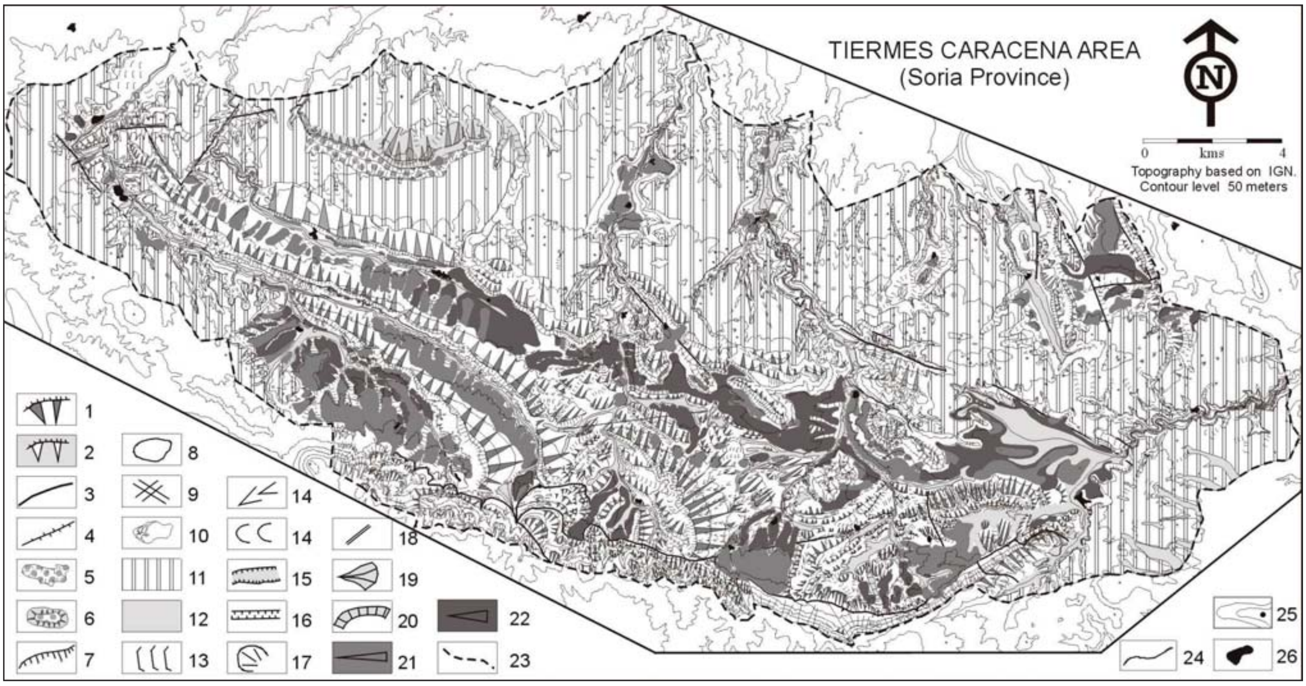

Fig. 2 – Geomorphological scketch of Tiermes-Caracena area. Legend: 1) Monocline ridge. 2) Monocline ridge on sandstones. 3) Faults. 4) Hog backs. 5) Orthocline valley. 6) Structural valley, Combe. 7) Structural scarp. 8) Dolines. 9) Karren. 10) Tufa. 11) Planation surface. 12) Fluvial terraces. 13) Fluvial flat bottom valley. 14) V-shaped fluvial valley. 15) Fluvial gorge. 16) Fluvial incision. 17) Erosional head. 18) Hanging valley. 19) Alluvial fan. 20) Fluvial palaeovalley. 21) Glacis, level 1. 22) Glacis, level 2. 23) Limit of study area. 24) River. 25) Contour level and peaks. 26) Villages.

— Schema geomorfologico dell'area di Tiermes-Caracena: Legenda: 1. Monoclinale nell'arenaria. 3) Faglie. 4) Hog backs. 5) Valle ortoclinale. 6) Valle strutturale, Combe. 7) Scarpata strutturale. 8) Doline. 9) Karren. 10) Tufi. 11) Superficie di pedeplanazione. 12) Terrazzi fluviali. 13) Valle fluviale a fondo piatto. 14) Valle fluviale con profilo a V. 15) Forra torrentizia. 16) Incisione fluviale. 17) Area in erosione. 18) Valle sospesa. 19) Cono alluvionale. 20) Paleovalle fluviale. 21) Glacis, livello 1. 22) Glacis, livello 2. 23) Confini dell'area di studio. 24) Fiume. 25) Curve di livello e rilievi. 26) Centri abitati.

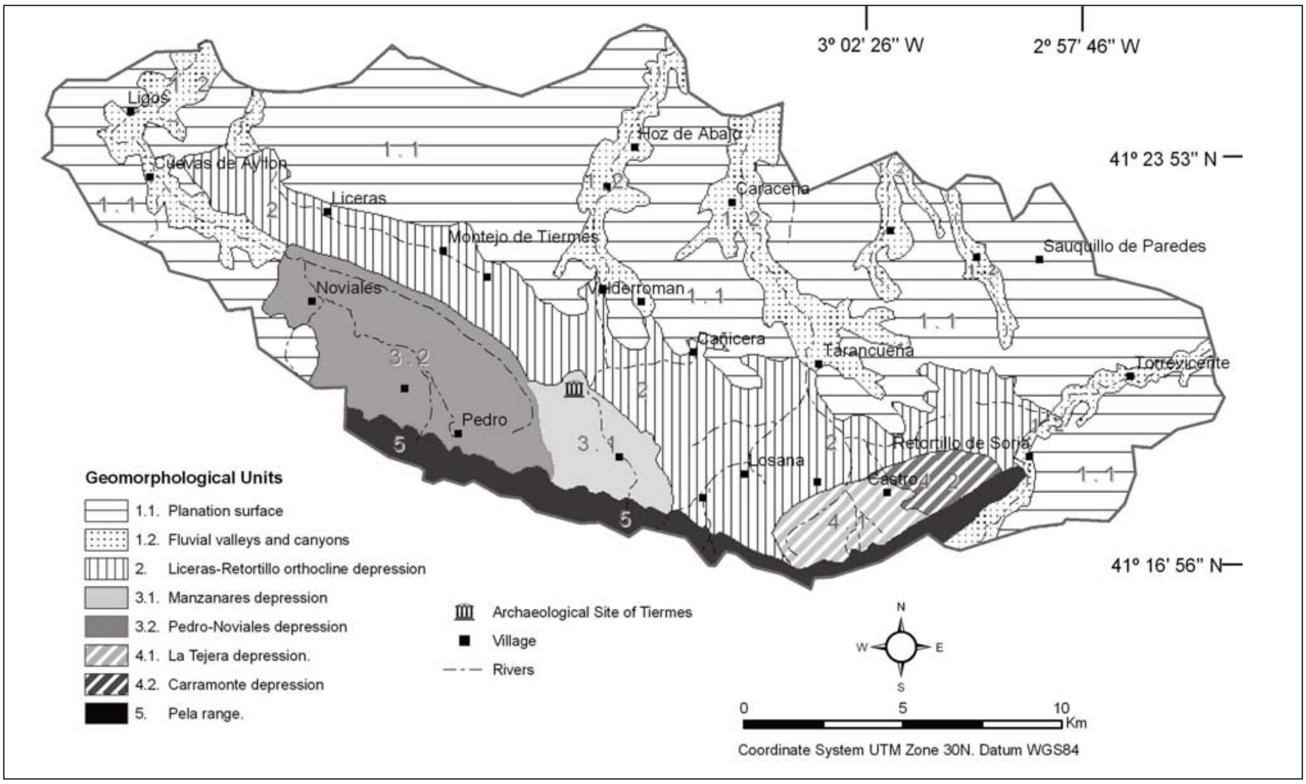

Fig. 3 – Geomorphological units of Tiermes-Caracena area.

— Unità geomorfologiche dell'area di Tiermes-Caracena.

Tab. 3 – *Geomorphological units and geodiversity index.*
– Unità geomorfologiche e indice di geodiversità.

Units	Unit name	Elements number	Surface (km2)	Roughness	Geodiversity Index	Geodiversity Value
1.1	Planation surface	23	184	1	4.4	Very low
1.2.1	Pedro Gorge	22	12	2.5	22.1	Low
1.2.2	Pozo Moreno Gorge	18	1	2.7	48.6	Very high
1.2.3	Tielmes Gorge	24	9	2.7	29.5	Middle
1.2.4	Caracena Gorge	30	15	3.2	35.4	High
1.2.5	Madruédano Valley	8	4	2.6	15	Low
1.2.6	Modamio Valley	14	3	2.5	31.8	Middle
1.2.7	Talegones Gorge	18	7	3	27.7	Middle
2	Liceras-Retortillo Depression	42	73	1.2	11.7	Very low
3.1	Pericline flank of Manzanares	24	11	2	20	Low
3.2	Pedro-Noviales Depression	26	32	1.7	12.7	Very low
4.1	Tejera Depression	20	8	1.8	17.3	Low
4.2	Carramonte Depression	20	5	1.5	18.6	Low
5	Pela Range	24	18	3.3	27.4	Middle

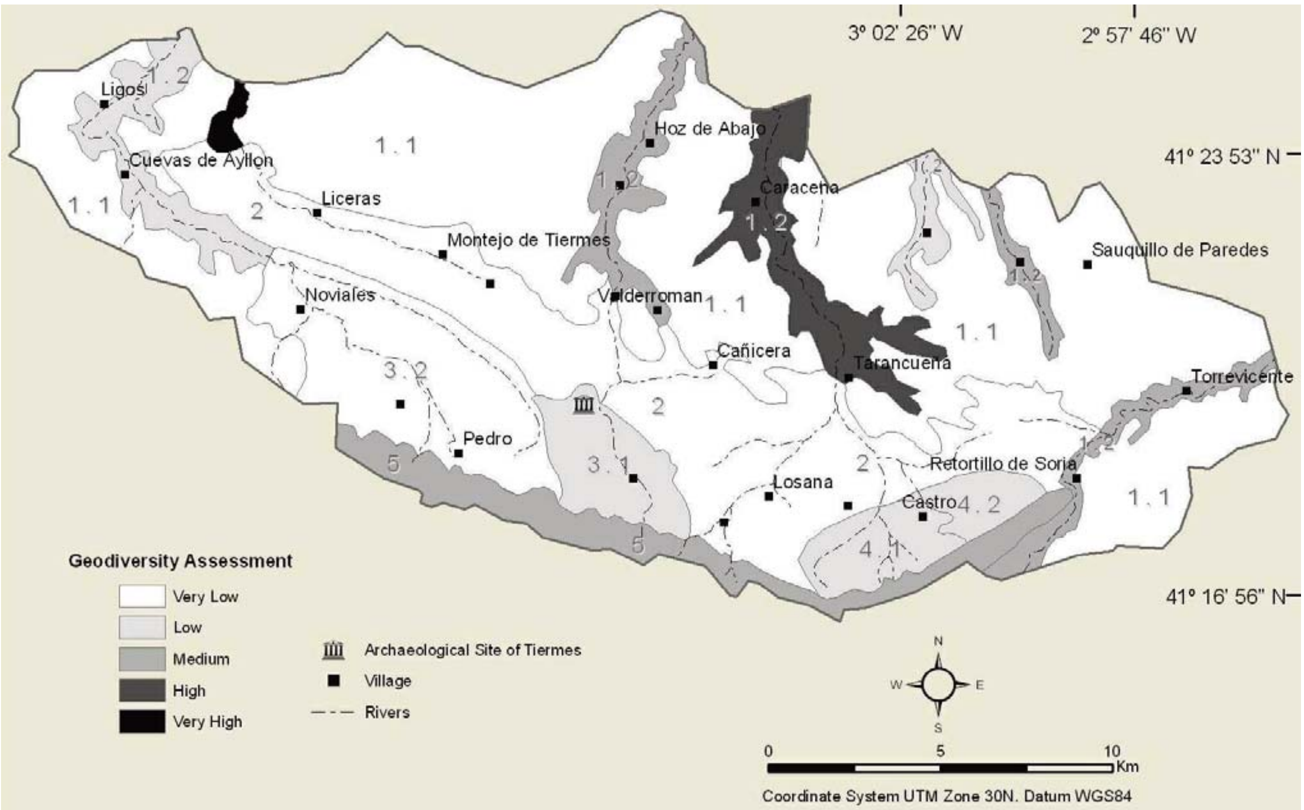

Fig. 4 – Geodiversity map of Tiermes-Caracena area.
— Carta della Geodiversità dell'area di Tiermes-Caracena.

5. – CONCLUSIONS

The assessment of geodiversity developed in this work has enabled us to establish five different classes from very high to very low. The methods used compound the physical elements (geology, landforms and processes, morphogenetic systems, hydrology and soils) with the roughness and surface area in a predetermined unit. The method can be applied to geomorphological or landscape units.

In the Tiermes-Caracena area the structural landforms, planation surface, and the fluvial and slope systems are dominant and have generated limited diversity of landforms, processes and soils. Once the index applied, it became clear that more than 75% of the territory had very low geodiversity, with wide surfaces and low numbers of elements and roughness. The results obtained reflect the internal homogeneity of the study area with low geodiversity but with areas (gorges and valleys) with higher values. All of them are close to the reality.

The index is easy to apply and enables comparisons to be made, on the same scale, between different territories. Nevertheless, the method must be confirmed in areas with more internal differences and until this is done the method must be used with caution. Some improvements should be included in further applications. We must point out the necessity to improve the calculation of roughness of units and of the relationships between surfaces and slopes. It is recognised that the index cannot be applied to small size units. Finally, the incorporation of other elements that increase geodiversity must be improved, such as palaeontology or micro-landforms. Regarding the latter, only its presence or absence has been considered in this work with a collective value, but in the future and in other areas or on other scales, it may be considered with individual values.

A quantitative approach to the assessment of geodiversity has been described, which may, in future, be used together with cultural, ethnographic and biological assessments by planners and managers for the better conservation of abiotic and geomorphologic values of the territory. The map of geodiversity, together with the indices, creates a useful tool for management.

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