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GEODIVERSITY: A NEW QUANTITATIVE INDEX FOR NATURAL PROTECTED AREAS ENHANCEMENT

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Abstract: In spite of the excellent results achieved by international scientific community, the topic of quantitative evaluation of geodiversity is still an open issue. The estimating models including the assessment of abiotic characteristics need to be improved by means of quantitative analysis of geological and geomorphological components. In this work an evaluation based on an Index of Geodiversity (Geodiversity Index, GI), easily inferable by GIS analysis, is proposed. The test area corresponds to the Subasio Mountain Regional Park (Umbria – central Italy), an excellent site for the abiotic components evaluation.

Key words: geodiversity, geomorphic analysis, GIS, Umbria, central Italy.

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INTRODUCTION

Natural heritage is the main renewable resource of Italy, due to the wide diversity characterising its physical landscapes. The complex geological and geomorphological setting, coupled with the variability of topographic and climatic features, trigger a dynamic evolution of natural systems. They are at the basis of the ecosystems survival, contributing to the uniqueness of the Italian territory.

The diversity of a natural ecosystem depends on biotic and abiotic components. Usually, the natural variability is identified with the biotic diversity, or biodiversity, whose short time development and evolution highlights the fragility of this component. Therefore, the scientific community, especially after the United Nations Conference on Environment and Development (UNCED), also known as „*the Rio Summit of 1992*", has devoted a great deal of attention to biodiversity enhancement and protection (Pimm et al., 1995; Myers et al., 2000; Petterson et al., 2013).

Although several scientists, mainly from northern Europe (Scotland, Germany, Switzerland), have focused on some geological rarity since the end of the 19th Century, only from a few decades geologists and geomorphologists have introduced the concept of geodiversity in the study of natural heritage. The close relationship between the abiotic and the biotic components has been investigated, including also the human presence and the related cultural heritage. Then, geodiversity was defined as „... *the link between people, landscape and culture, the variety of geological environments, components,*

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phenomena and processes that constitute them showing in a variety of rock types, minerals, fossils, and soils that provide the frame of life on Earth" (Stanley, 2002). Over the years, geodiversity was defined as "*the natural range (diversity) of geological (rocks, minerals, fossils), geomorphological (landforms, physical processes) and soil features*" (Gray, 2004). Later, also topographic and hydrographic elements were introduced in this definition (Serrano & Ruiz-Flaño, 2007a, b; Gray, 2008).

The values of geodiversity were separated into four groups (Gray, 2004). The first was referred as to the intrinsic value or "*the ethical belief that some things (in this case geodiversity) are of values simply for what they are rather than what they can be used for by humans (utilitarian value)*" (Gray, 2004).

The second was the cultural and aesthetic value assigned by a community for which a particular site plays an important role in terms of cultural and historical heritage; the third was the economic aspect, as the geodiversity can be an economic resource, sometimes of prime importance for the areas in which it is recognized. The last one was the scientific and educational value: the importance of geodiversity as a topic of scientific research, teaching and dissemination.

Other authors (Panizza & Piacente, 2008) defined the geodiversity value as:

1. intrinsic, according to the geological complexity of the study area;
2. extrinsic, in relation to geological differences when compared to other areas;
3. simple, covering the whole range or the diversity of geological objects in an area without value attribution;
4. complex, referred to specific geological systems with an high diversity.

Hence, it is clear the geodiversity is the essential starting point to guarantee not only the biodiversity, but also the entire natural diversity of physical landscape.

Several authors highlighted that this aspect has always played a secondary role, both in scientific fields and in administrative decisions and legislation on environmental protection (Milton, 2002). This is even less understandable when we consider that areas with an high value of geodiversity are at risk, too often underestimated (Lazzari et al., 2006; Kiernan, 2010). Human pressure, accelerated erosion, indiscriminate exploitation of natural resources are the main causes for hazard increasing.

Recently, several studies (Fronzek et al., 2006; Prosser et al., 2010) have shown a real risk related to the geodiversity losing. This is particularly evident in areas where global climate change modifies temperature and rainfall values trend, increasing the effectiveness of morphogenetic processes. For this reason, the only realistic possibility to preserve the geological heritage is to sensitize and influence the political actions. So, after the art. 2 of the Convention on the Protection of World Cultural and Natural Heritage (UNESCO) signed in Paris in 1972, the international scientific community started to identify areas with high value of geodiversity, basing on the definition and identification of „*geosites*" or any place, area or territory representing a rarity of geological and geomorphological events with a consequent interest for conservation. In Italy, this has resulted mainly in the identification of geosites, geological routes and geoparks foundation (Poli, 1999; Carton et al., 2005; Gregori & Melelli, 2005; Gregori et al., 2005; Reynard & Panizza, 2005; Reynard & Coratza, 2007).

Nowadays, the geodiversity definition, evaluation and recognition represent some of the most important targets for Earth Sciences. However, despite the excellent results achieved by scientific national and international research, the quantitative assessment of this parameter is still an open field.

To this aim, some quantitative models have been proposed (at medium and small scale) although the number of scientific works on the subject is still low (Ibáñez et al., 2005, Serrano & Ruiz-Flaño, 2007a, b; Jačková & Romportl, 2008; Benito-Calvo et al., 2009; Hjort & Luoto, 2010). It is to note that most of these works are far to propose a unique method that can be consistently used for a territory holding so many different characteristics like Italy (Massoli-Novelli & Petitta, 2001; Panizza, 2009; Giardino et al., 2012).

The idea that we put forward here is to develop a quantitative formulation which is able to define the components related to terrain data from a geometric-morphometric point of view rather than a semantic one (Pike, 1995; Goudie, 2004; Taramelli & Melelli, 2009 a, b). To this aim, the Geographic Information Systems (GIS) appear the most straightforward analytical tools that can take into account quantitatively the spatial relationships between study objects to define numerical indices (Melelli & Floris, 2010).

With this paper we aim at contributing to produce a spatial analysis tools that might become an incentive for the scientific, cultural and economic development for the identified areas.

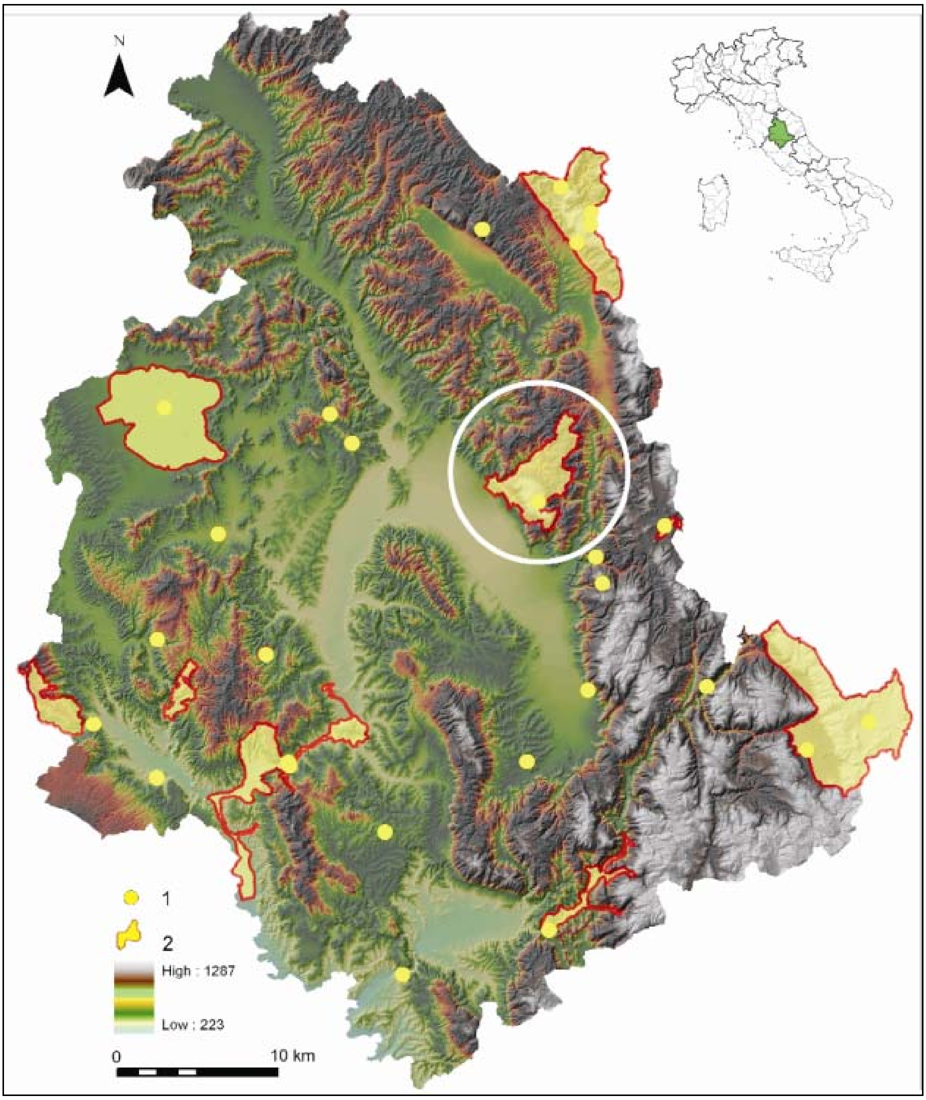

Figure 1. Location map of the Umbria Region (central Italy). The white circle marks the Subasio Mt. Regional Park. (1) Geosites, (2) Regional Parks

THE TEST AREA: SUBASIO REGIONAL PARK (CENTRAL ITALY)

Subasio Mountain regional Park is located in Umbria (central Italy), a region with a well known natural heritage, where twenty-seven geosites are already individuated and studied. This region also hosts seven regional and one national natural park (Figure 1).

The Subasio Mt. Park covers a surface area of 7.200 hectares and is delimited southward by the homonymous mountain (1.290m a.s.l.). To the west the boundary follows the Tescio River, bordering gentle slopes where terrigenous formations crop out. The litotypes of this area can be clustered into three main complexes; several different types of overlying Holocene deposits (alluvium, colluvium, debris and landslide bodies) are also widespread (Figure 2, Melelli et al., 2012).

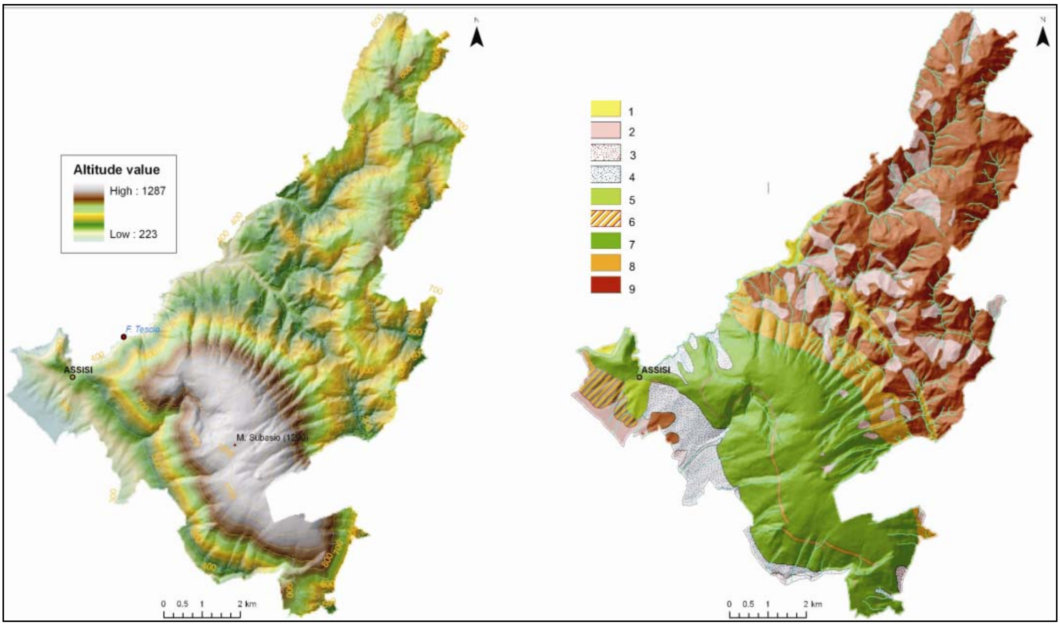

Figure 2. Left: DEM of Subasio Mountain Regional Park (altitude values in meters a.s.l.) Right: geological map: (1) Alluvial deposits, (2) Colluvial deposits; (3) Debris deposits (active); (4) Debris deposits (ancient); (5) Fluvial Lacustrine complex; (6) Travertine; (7) Calcareous complex; (8) Terrigenous complex with prevalent clay; (9) Terrigenous complex with prevalent sandstone

The calcareous Complex (upper Trias – Oligocene) crops out in the southern sector, on slopes of the rounded antiformal ridge of Subasio Mount. The terrigenous complex (Miocene) is divided in two parts, depending on the clay percentage, and covers the leftover of the study area. The surface deposits (Pliocene – Holocene) have different genesis, fluvial-lacustrine the most ancient, debris, colluvial and alluvial the recent ones. Despite the test area is quite limited in its extension, a great variety of lithotypes crop out, involving a very diversified morphological arrangement. The highest altitude and amplitude of relief values are on the calcareous complex, whereas the terrigenous formations show gentle slopes, occasionally cut by deep and narrow valleys.

From a geomorphological point of view (Figure 3), karst landforms occur on the top of Subasio Mt., with large dolines locally named "*mortari*". The leftover of the antiformal ridge is characterized by structural and fluvial landforms. The main part of the park area is characterized by an active morphogenesis with fluvial features, both erosional and depositional, due to the high erodibility of the terrigenous formations. There are also a significative number of mass movements along the Subasio Mt. slopes.

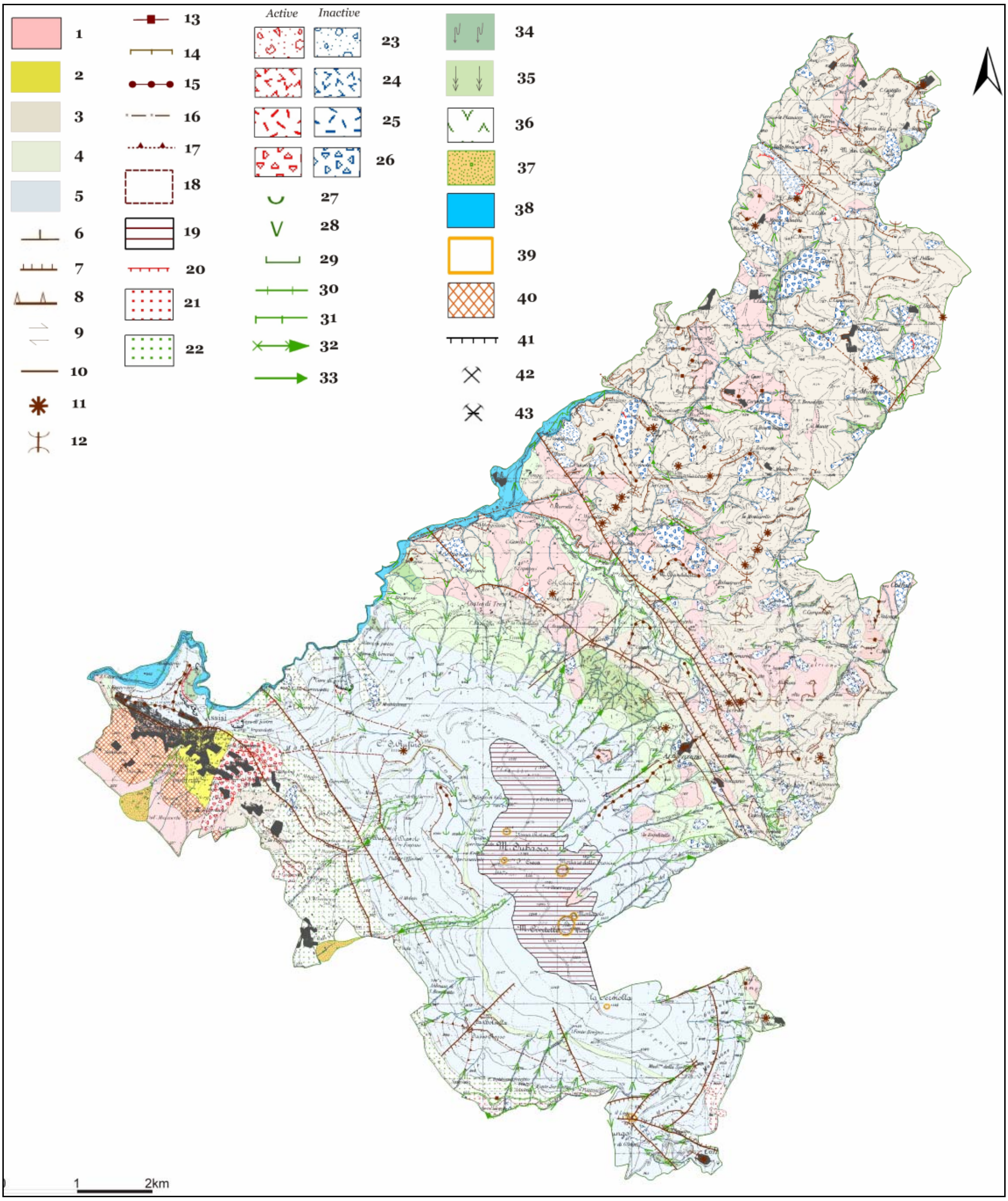

Figure 3. Geomorphological map of Subasio Mountain Regional Park (Melelli et al., 2012) 1) Colluvial deposits, 2) Fluvial lacustrine deposits, 3) Terrigenous complex (sandstone > clay), 4) Terrigenous complex (sandstone < clay), 5) Calcareous complex, 6) Dip direction, 7) Normal fault, 8) Inverse fault, 9) Transcurrent fault, 10) Fault, 11) Peak, 12) Saddle, 13) Break slope, 14) Escarpment, 15) Ridge, 16) Lineation, 17) Flatiron, 18) Triangular facet, 19) Structural surface, 20) Gravitational escarpment, 21) Debris (actual), 22) Debris (recent), 23) Flow, 24) Slide, 25) Fall, 26) Complex, 27) U shaped valley, 28) V shaped valley, 29) Flat bottom valley, 30) Gorge, 31) Fluvial escarpment, 32) Gully erosion, 33) Elbow, 34) Sheet erosion, 35) Gully erosion, 36) Badland, 37) Alluvial fan, 38) Alluvial deposits, 39) Dolina, 40) Travertine, 41) Anthropic escarpment, 42) Quarry (active), 43) Quarry (inactive)

Due to the variety of lithotypes, covering deposits and geomorphological processes, the study area represents an excellent natural laboratory to test the geodiversity influence on the landscape aspect and evolution. Moreover, the Subasio Mt. Park is characterized by high cultural and architectural values, such as the town of Assisi, with the marvelous basilica declared as a UNESCO world heritage site and numerous historical and religious sites, assuring to this area a steady flow of tourists and pilgrims from all over the world.

GEODIVERSITY INDEX (GI) EVALUATION

The spatial analysis in GIS makes use of numerical methods that compare spatial data in vector format (geometric elements that shape the geographic reality in points, polylines or polygons) and grid (raster, in a matrix format with resolution equal to the side of the cell, associating a spatial attribute to each cell).

The formula for Geodiversity Index (or GI) evaluation, as amended by Serrano & Ruiz-Flaño (2007a; b) is the following [1]:

$$GI = \frac{\left[\left(\sum_{i=1}^{n} V_i\right) + \left(\sum_{i=1}^{n} G_{mi}\right)\right]\left(\frac{S_a}{P_a}\right)}{\ln S_a} \qquad [1]$$

Where:

V_i (Variability function) is each abiotic factor contributing to the geodiversity definition with intrinsic characteristics of spatial continuity (i.e. lithotypes, land use classes);

G_{mi} (Geomorphology factor) is each abiotic factor contributing to the geodiversity definition with intrinsic characteristics of spatial discontinuity (geomorphological features, landforms);

S_a (Surface area) is a raster in which the cell values reflect the true topographic surface area within that cell;

P_a (Planimetric area) is the square of the resolution of the Digital Elevation Model (DEM) representing the topographic surface.

The data used to calculate V_i in [1] include: geological data in vector format deriving from the map of geological complexes (Figure 2) and land use in vector format from the Corine Land Cover project (scale 1:100.000; EEA, 2007). Each theme is converted into a grid where the variability of the data is calculated in a moving window (a circle of radius equal to 75m), using neighborhood analysis and a focal statistics function. The statistical calculation of the values contained within the moving window, repeated for each cell, is shown as output in the central cell of the window, then the grid is reclassified in three classes with an increasing degree of variability (Figure 4). This type of analysis is possible according to the spatial continuity of the data (there are no areas with -no data- in a geological map or in a land cover one).

The second term (G_{mi}) is the sum of abiotic factors (with no spatial continuity in the mapping process). The geomorphological data can be represented in some vector layers, corresponding to the different landform units, and then converted in a grid format. The conversion creates layers without continuity, being several -no data- values between the landforms. Furthermore, two or more geomorphological processes can be present in the same spatial location (cell). As an example, on the top of the Subasio Mt., some macro-dolines are superimposed on a structural surface. Due to the different and very complex representation of this kind of data, a different spatial analysis is used. All the landforms belonging to one morphogenetic process are merged. Then, all the layers corresponding to geomorphological processes acting in the study area are summed by local functions “*plus*” and then the output layer is reclassified (Figure 5).

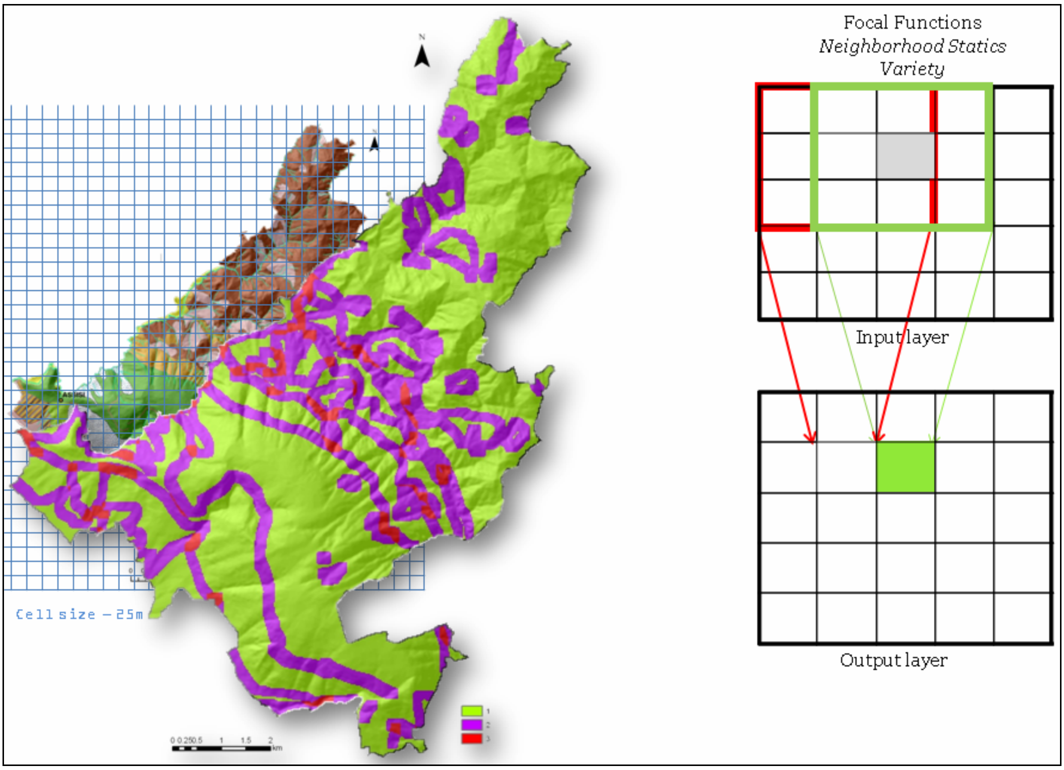

Figure 4. The neighborhood function "*variety*" determines the number of unique values (or variety) for each cell location on an input raster within a specified neighborhood and sends it to the corresponding cell location on the output raster

The highest values of G_{mi} correspond to the areas where multiple and simultaneous morphogenetic processes occur.

The remaining parameters, expressed by Sa (surface area) and Pa (planimetric area) enhance the role of topographic factor in the geodiversity estimation and are directly calculated from a Digital Elevation Model (DEM). Irregular topographic surface, with high values of terrain roughness (a term used to describe how "*irregular*" an area is) identifies zones where depressions and ridges are alternated in a short distance, that may be due to causes related to a more complex geological structure, and/or to different type and effectiveness of geomorphological processes. Summarising: the higher the roughness, the more is the erosion intensity and, therefore, the higher the density of landforms.

The roughness is derived from a DEM with a 25x25m cell size, according to the same spatial resolution of the other grid data. The topographic indexes (Sa, Pa) are computed using the „*Surface Area and Ratio*" tool for ArcGIS (Jenness, 2004). In detail, Sa is a raster in which the cell values reflect the real topographic surface area within that cell, directly proportional to terrain irregularity and therefore higher in mountainous areas and lower in flat ones. Pa corresponds to the square of the resolution of the elevation model. The ratio between Sa and Pa is taken as a measure of topographical irregularity or roughness (Jenness, 2004).

The final step is to apply the formula in a procedure of spatial analysis, overlaying the datasets of variability; each data must be classified in three classes, to assure the same weight to each layer (Figure 6).

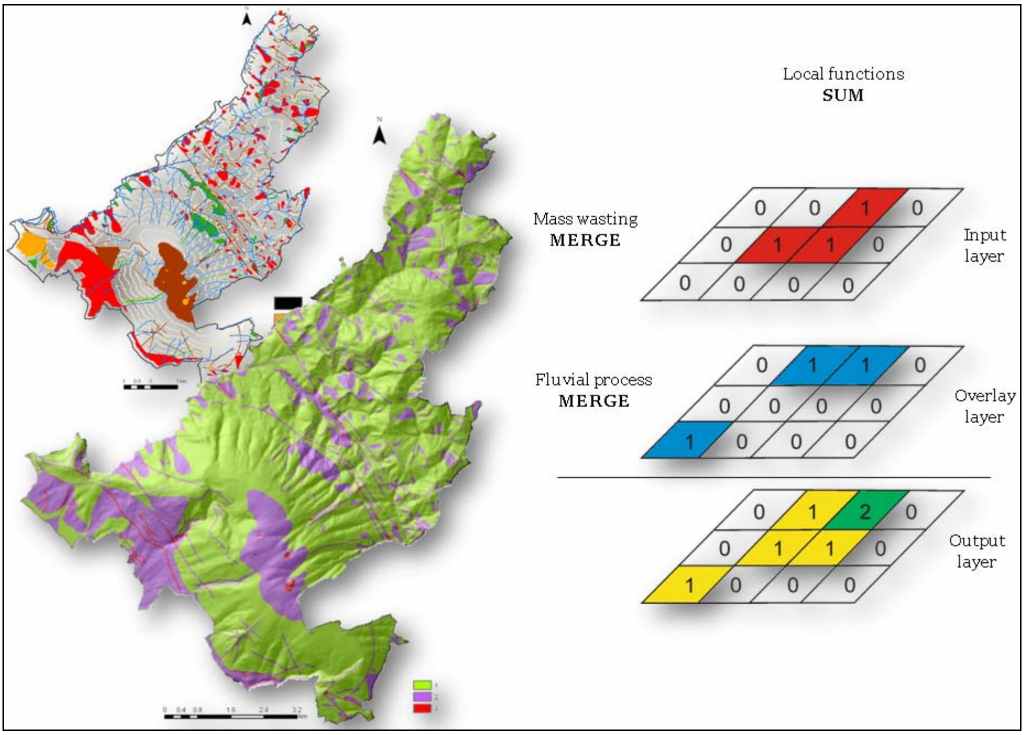

Figure 5. G_{mi} as the sum of geomorphological data. All the layers corresponding to geomorphological processes acting in the study area are summed by local functions "*plus*" and then the output layer is reclassified in three classes with a decreasing degree of variability.

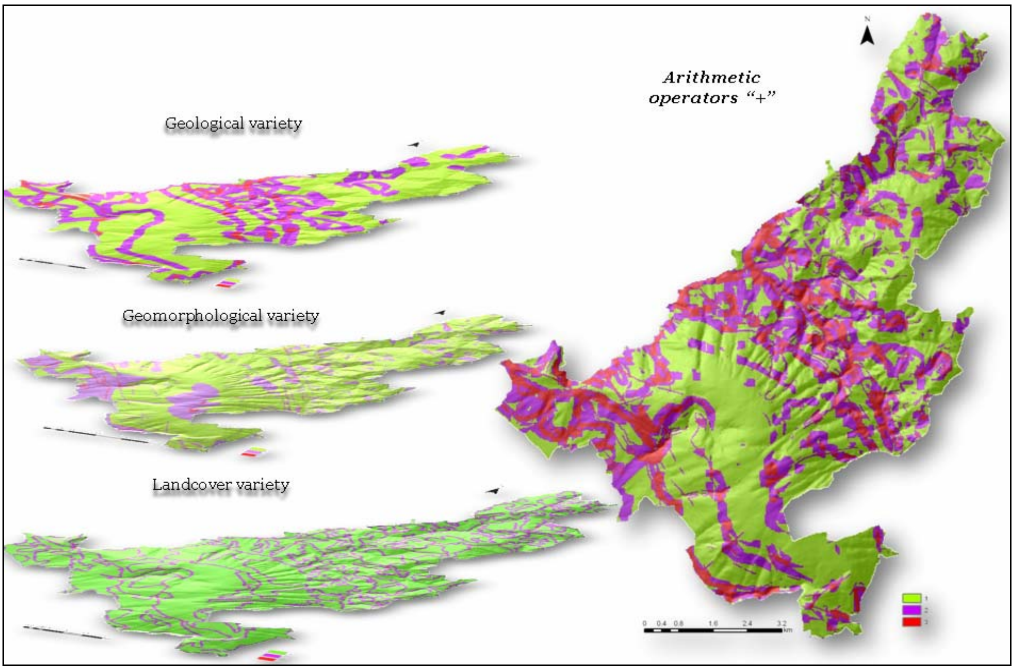

Figure 6. Overlapping input themes. On the right, the resulting grid of geodiversity index

The resulting Geodiversity Index map of regional park of Subasio Mountain is classified in three classes with null or low, medium and high geodiversity value as shown in Figure 7.

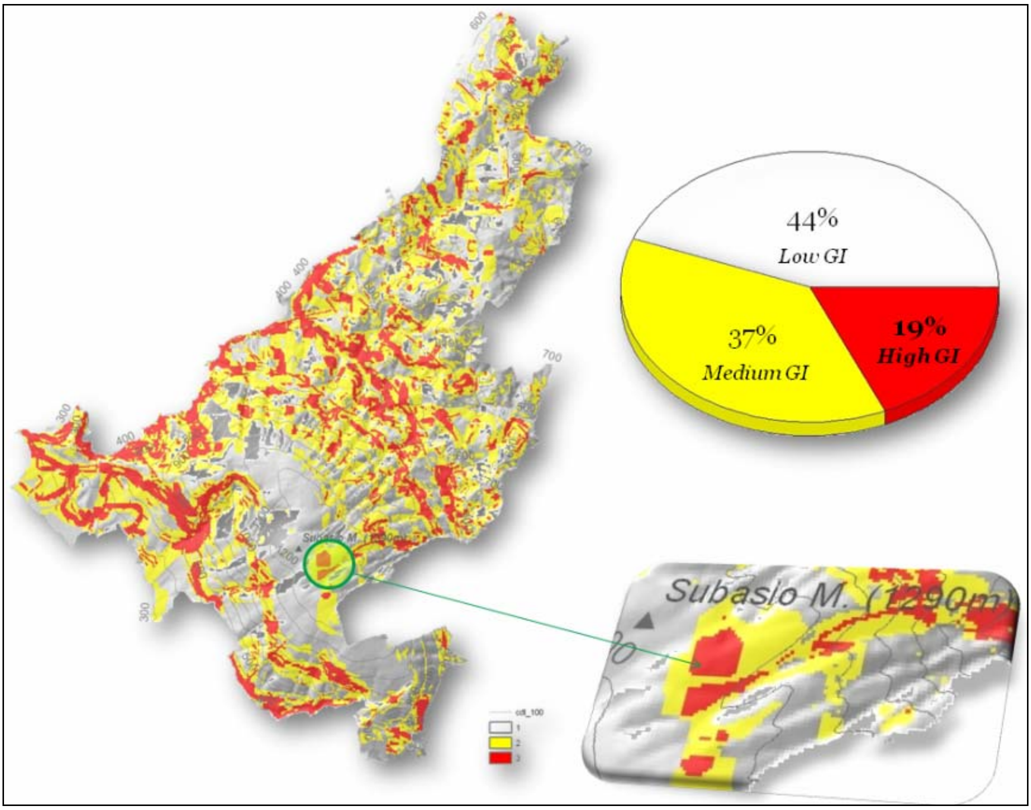

Figure 7. The Geodiversity Index map for the Subasio Mt. Regional Park
1) Null or low value, 2) Medium value, 3) High value. The lower right enlargment
shows high GI values corresponding to macro-doline (geosites).

The reclassification assigns the break values according to natural groupings inherent in the data. Class breaks are identified where similar values are best grouped and where the breaks maximize the differences between classes, as a result the boundaries classes are set where the highest differences in the data values are present (De Smith et al., 2006/9). Nineteen percent of the territory is characterized by a high value of geodiversity and the thirty-seven percent with a medium value. The maximum Geodiversity Index value is confined in particular topographic and geomorphological assessments. High value of geodiversity matches the geosites like the macro-doline on the top of the Subasio Mountain or where two or more geomorphological processes are acting. Moreover, the same classes correspond to high values of topographic index where the morphogenesis is faster. In addition, these areas correspond also to zones where an intense fluvial deepening is carving several gorges in the terrigenous complex.

FINAL REMARKS

The management of natural parks and protected areas can find in the improvement of the abiotic component a new impulse for environmental enhancement. Geodiversity is the starting point that can guarantee the variability of an ecosystem and the survival of unique landscapes and, above all, of different forms of plant and animal life (biodiversity). Geodiversity is strictly linked to the presence of geosites and, in the natural parks, it is a necessary condition to promote the protected areas. Indeed, according to geoparks definition, a geopark is a territory which includes a meaningful geological heritage and a sustainable territorial development strategy. To this aim, an unbiased evaluation of the geodiversity is an essential tool to assess the effective presence/absence of abiotic heritage.

In order to evaluate the geodiversity, qualitative remarks are well defined and widely available in scientific literature; however, a quantitative method is advisable. This approach assures the advancement of knowledge on the identification of geodiversity for the development of the natural heritage.

It is also an additional method which can be in principle used in different areas, a final upgradable digital database, a tool to identify areas with potential value of the abiotic component, and an instrument for economic development and conservation management. The aim is to predict potential evolution and transformations of land uses and planning the proper management of natural heritage.

Concluding, in this paper a GIS analysis method is described, where different spatial analysis tools are used, in order to obtain a digital dataset that parceled the test area in three classes of geodiversity (null or low, medium and high).

This approach might aid in achieving important objectives, such as the implementation of a computational model for geodiversity at different scales, a better definition of the parameters defining geodiversity, and an unbiased procedure to build a model of spatial analysis in the GIS environment, suitable for an automatic determination of the Geodiversity Index.

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