A Spatial Method for the Geodiversity Fragmentation Assessment of Basilicata Region, Southern Italy

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Abstract. The heterogeneity of the abiotic factor, or geodiversity, is an important issue for the landscape genetics. In this paper, a spatial method for the assessment of the geodiversity of Basilicata region in southern Italy is proposed through the use of fragmentation indexes. The fragmentation indices use the values derived from the overlay of three different maps: i) landform map; ii) climate map; iii) geological map. Three indexes have been applied to obtain the geodiversity of the study area: i) Shannon's diversity index (SHDI); ii) Shannon's Evenness Index (SHEI); iii) Simpson's Diversity Index (SIDI). The results show how the three indices offer similar results. High values of geodiversity can be observed: i) in the frontal sector of the chain; ii) where the complexity of the landscape forms is high. Low values of geodiversity are observed in the Ionian coast belt. These results can represent a basic but valuable tool for the delineation of the main macro-areas with different geodiversity values.

Keywords: Geodiversity · Spatial analysis · Landform classification · Climatic classes · Fragmentation indexes · Basilicata region (southern Italy)

1 Introduction

Geodiversity is defined as the "diversity of the earth features and systems" [1]. Its conservation or "Geoconservation" is important: 1) by its own right; 2) for the appearance of a landscape; 3) for the planning and the management of many territorial aspects; 4) for contributing to the conservation of the ecological systems and consequently for sustainability. Quantitative assessment of the regional geodiversity of a landscape can represent a valuable parameter for the identification of homogeneous sectors of wide and complex geological and morpho-climate landscapes. In literature there many attempts to calculate a geodiversity map, in different geodynamics and morpho-structural contexts (see for example [2, 3]).

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Even if geodiversity maps are diffused and calculated also by different national or local Agencies, however, nowadays, a unique method for the geodiversity calculation does not exist.

In this paper the geodiversity is estimated by spatial analysis methods as a combination of three physical aspects of Basilicata region, a 10,000 km^2-wide region of southern Italy: 1) the landform classes, 2) the climatic zones and 3) the geological features. The study area includes a relatively narrow transect of the southern Apennine chain, where poly-deformed litho-structural units belonging to different domains of the chain, clastic deposits of Pliocene to Quaternary tectonic basins and foredeep areas, and carbonate of the Apulia foreland coexist. Such a wide richness in terms of morpho-tectonic domains, litho-structural features, and landform variability can represent a valuable peculiarity for the identification of areas prone to the development of sustainable geotourism. The geodiversity fragmentation is assessed through the use of well-known fragmentation indexes and was summarized in regional scale maps.

2 Case Study

The southern Apennines are a northeast-verging fold-and thrust belt mainly composed of shallow-water and deep-sea sedimentary covers, deriving from Mesozoic–Cenozoic circum-Tethyan domains, covered by Neogene-Pleistocene foredeep and satellite-basin deposits [4] (Fig. 1). These units formed the backbone of the chain and overthrust on the Apulia carbonate of the foreland area.

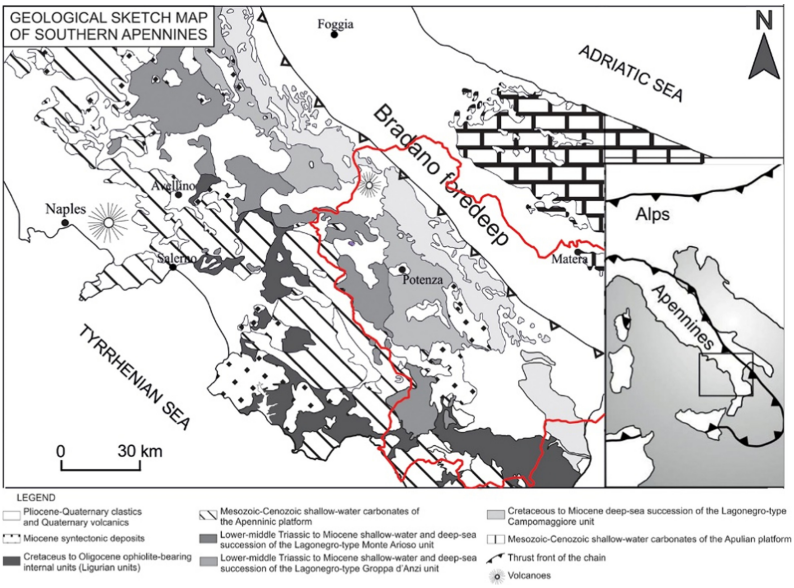


Fig. 1. Study area location

Contractional structure of the belt was dismember by high-angle faults, which are responsible for i) the formation of longitudinal and transversal fault-bounded basins [5–7], ii) the displacement of several generations of planation surfaces [5, 8], and iii) the re-organization and control of many hydrographic networks [5, 9, 10].

3 Parameters and Methods

The method used to assess geodiversity fragmentation consisted of the combination of three main elements: the map of landforms of Basilicata region, the map of climatic areas obtained by using climate data, and the map with the main lithological/geological classes of the study area.

Results are summarized in three fragmentation index map in order to assess the fragmentation degree of the Basilicata region landscape. In the following paragraphs, the methods and the parameters used to calculate each of the three elements are explained.

3.1 Landform Calculation

The first step consisted of the automatic landform classification. Many methods exist in literature, and each method uses different criteria, resolution of the input data, number of variables, and algorithms. Some of these were also compared in selected sectors of the study area to understand which one is more effective [11, 12] and test that a reliable method is linked to the concept of "geomorphon", developed by [13].

In such a method, a pattern-based classification that self-adapts to the local topography is used, through the construction of Local Ternary Patterns (LTM), also called geomorphons. These are the basic micro-structures that form any type of morphological classes. Consequently, landform classes are extracted from LTP and their combination [13].

In the method of geomorphons, the main parameters are: 1) the input DEM; 2) the flatness threshold that defines which slope should have areas to consider flat; 3) the inner and outer search radius. For Basilicata region DEM with a resolution of 5 m was used. The flatness threshold was imposed equal to 5°, while the inner and outer radii were imposed equal to 25 m and 500 m, respectively.

The resulting landform map consists of ten classes, as shown in Fig. 2. Table 1 shows the area and percentage distribution data from each of the ten classes in the study area, the main landform is the slope one, which covers 31% of the study region (Table 1).

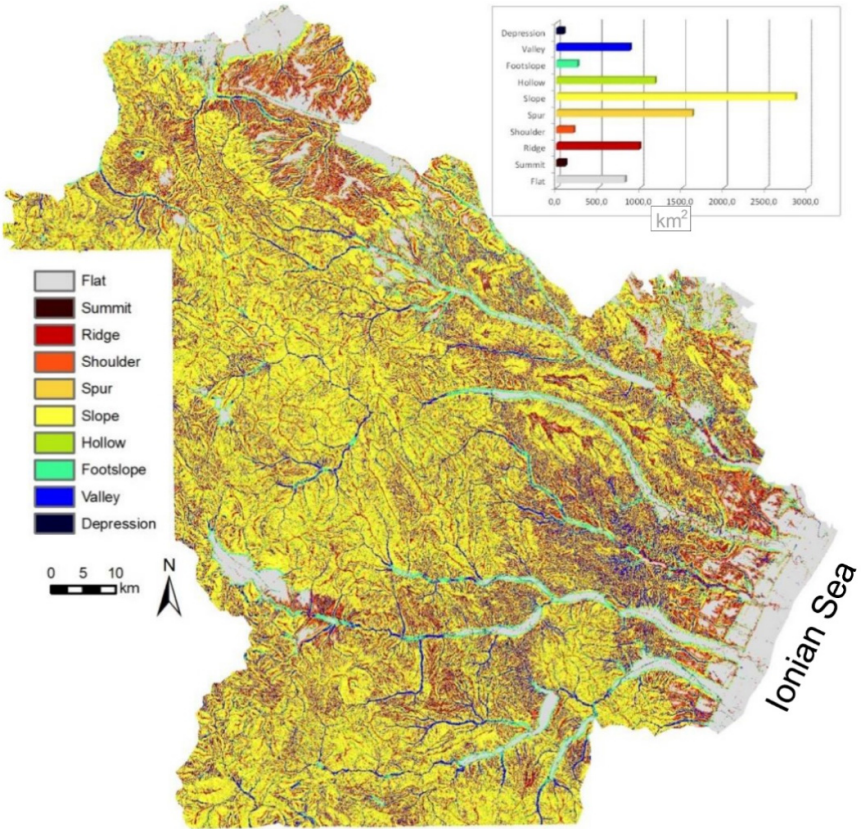


Fig. 2. Landform classes calculated with the method of geomorphons.

3.2 Climate Classification

The second step is represented by the delineation of the main climatic zones of the study area. To this aim, the criteria of Koppen classification was used (see [14] for more details). It allows to define climatic zones by using mean precipitation and temperature data (Table 2).

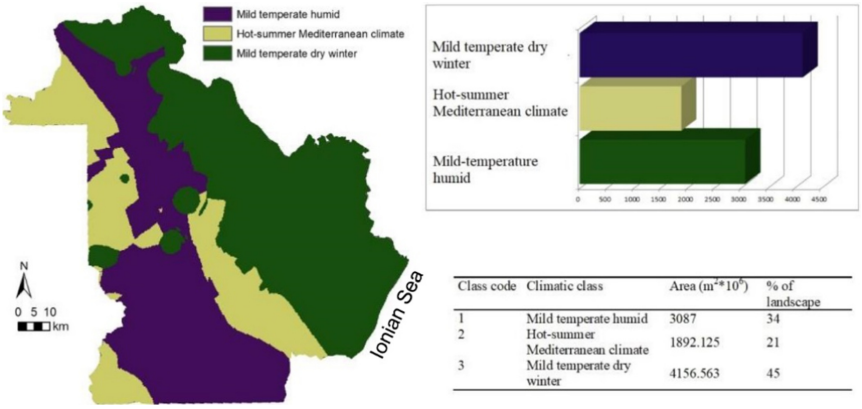
Data on rainfall and temperatures were taken from the site of the Functional Centre of Basilicata region and then they were interpolated using universal kriging. The resulting 5 m cell-sized maps were combined in order to apply the Koppen classification, which revealed 3 climatic zones (Fig. 3) in the general cluster of the temperate climate group: a mild temperate humid zone, a mild temperate dry winter zone, and a hot-summer Mediterranean climate.

Table 1. Landform classes distribution in Basilicata region.

Landform code	Landform	Area ($m^2 * 10^6$)	% of landscape
0	Flat	819.0	9.1
1	Summit	108.0	1.2
2	Ridge	989.7	11.0
3	Shoulder	201.8	2.2
4	Spur	1623.9	18.1
5	Slope	2854.2	31.8
6	Hollow	1177.2	13.1
7	Footslope	250.1	2.8
8	Valley	874.8	9.7
9	Depression	86.8	1.0

Table 2. Koppen climate classes (T_i = average temperatures of each month from January to December; P = precipitation). Our study region showed only three classes: Cwa (Mild temperate dry winter), Cfa (Mild temperate humid) and Csa (Hot-summer Mediterranean climate).

Type/Subtype	Criteria Rainfall/temperature regime
A - Tropical climates	$T_{min} \geq 18°C$
B – Dry climates	70% P_{ann} falls in summer months and $P_{mean\ ann} < 20T + 280$; 70% P_{ann} falls in winter and $P_{mean\ ann} < 20T$; 70% P_{ann} falls in summer months and $P_{mean\ ann} < 20T + 140$;
C - Temperate climates	$0 < T_{i\ min} < 18°C$ & $T_{i\ max} > 10°C$
w	$P_{driest\ winter} < P_{wettest\ summer}/10$
s	$P_{driest\ summer} < 30mm$ & $P_{driest\ summer} < P_{wettest\ winter}/10$
f	Precipitation distributed throughout year. Neither w or s
a	$T_{warmest\ month} \geq 22°C$
b	Four of the $T_{warmest\ month} \geq 10°C$ & $T_{warmest\ month} < 22°C$
c	Three of the $T_{warmest\ month} \geq 10°C$ & $T_{warmest\ month} < 22°C$
D – Continental climates	$T_{i\ min} < 0°C$ & $T_{i\ max} > 10°C$
E – Polar and alpine climates	$T_i \leq 10 \quad \forall\ 1 < i < 12$



Class code	Climatic class	Area (m^2*10^6)	% of landscape
1	Mild temperate humid	3087	34
2	Hot-summer Mediterranean climate	1892.125	21
3	Mild temperate dry winter	4156.563	45

Fig. 3. Climate classes of the study area.

3.3 Geological Data

In the third step, the geological map was delineated through a revision of the official geological cartography (Fig. 4). The map includes data from different geological maps at different scales and the definition of the main lithological complexes classes was carried out taking into account three different characteristics: 1) type of rock; 2) formation/sedimentation environment; 3) location in the frame of the main domains of the chain. A code was assigned and the area occupied by each class was estimated (Table 3).

3.4 Geodiversity Map

The landform, climatic and geological maps were combined with the help of map algebra. The resulting raster map was estimated as follows:

$$C \cdot 10^3 + L \cdot 10^2 + G \cdot 10^0 \quad (1)$$

where C is the climatic class, L is the landform, G is the geology. The three rasters were summed in order to obtain a geodiversity map characterized by numerical categories, where the first left digit represents the climatic class, the second one represents the landform type, and finally the last two digits represent the geology. In this way, even if 281 classes were obtained, that are not clearly distinguishable by the human eyes, the raster is an information system, where in each pixel it is possible to query and know the different elements of the landscape.

For example, in the class 1312, we have the morphogenetic zone 1, the landform class 2 and the geologic category 12.

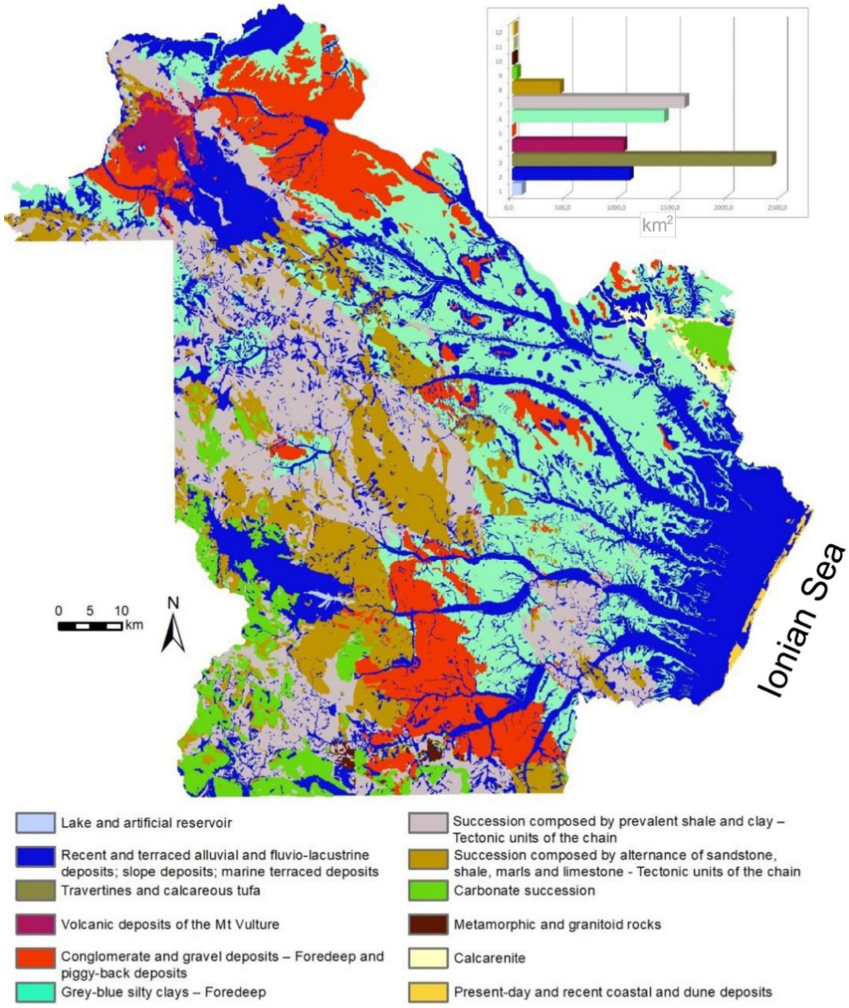


Fig. 4. Lithological/geological units of the study area.

Table 3. Distribution of geological classes in Basilicata.

Geology code	Geology	Area ($m^2 * 10^{-6}$)	% of landscape
0	Lake and artificial reservoir	94.4	1.1
1	Recent and terraced alluvial and fluvio-lacustrine deposits; slope deposits; marine terraced deposits	1095.7	13.3
2	Travertines and calcareous tufa	2420.2	29.4
3	Volcanic deposits of the Mt Vulture	1039.9	12.6
4	Conglomerate and gravel deposits – Foredeep and piggy-back deposits	3.1	0.04
5	Grey-blue silty clays – Foredeep	1419.2	17.02
6	Succession composed by prevalent shale and clay – Tectonic units of the chain	1610.9	19.5
7	Succession composed by alternance of sandstone, shale, marls and limestone - Tectonic units of the chain	449.8	5.5
8	Carbonate succession	48.5	0.6
9	Metamorphic and granitoid rocks	22.5	0.3
10	Calcarenite	19.3	0.2
12	Present-day and recent coastal and dune deposits	20.0	0.2

3.5 Fragmentation Indexes

For the fragmentation analysis and the geodiversity assessment three indexes were used: the Shannon's Diversity Index [15] (SHDI), Eq. 2; the Shannon's Evenness Index (SHEI), Eq. 3; the Simpson's Diversity Index (SIDI), Eq. 4 ([16] and references therein).

$$SHDI = -\sum_{i=1}^{n} (P_i lnP_i) \tag{2}$$

$$SHEI = -\sum_{i=1}^{n} \frac{(P_i lnP_i)}{lnn} \tag{3}$$

$$SIDI = 1 - \sum_{i=1}^{n} P_i^2 \tag{4}$$

In the Eqs. 2, 3 and 4, n is the number of classes, also called, in this type of analysis, patch units. P_i is, instead, the proportion occupied by the i class over the study area.

Each index has a different range:

- the SHDI index is, without an upper limit, greater or equal to 0;
- the SHEI ranges between 0 and 1;

- the SIDI ranges between 0 and 1.

The SHDI and the SIDI express the richness of diversity (also called entropy degree in [15] and how it is quantitatively composed and distributed, by considering the number of different classes in a specific area and the surface by them occupied. These indexes can be calculated globally or locally. In this paper, a local version of the indexes was chosen and calculated. The shape of the local area of calculation is a circle with a radius of 1 km. Even if both SHDI and SIDI assess richness, SIDI highlights mainly the most common classes present in the distribution.

The SHEI index, instead, is useful to quantify how much the classes are even between them and where even classes are distributed. Also for this index, the local version was used, again by choosing a circular shape and a radius of 1 km.

4 Results and Final Considerations

The geodiversity obtained for the investigated region using the Shannon diversity index (SHDI) shows an interval between 0 and 3.25 (Fig. 5). High diversity values are observed: 1) in the frontal sectors of the chain; 2) along the ridges that divide the catchment areas

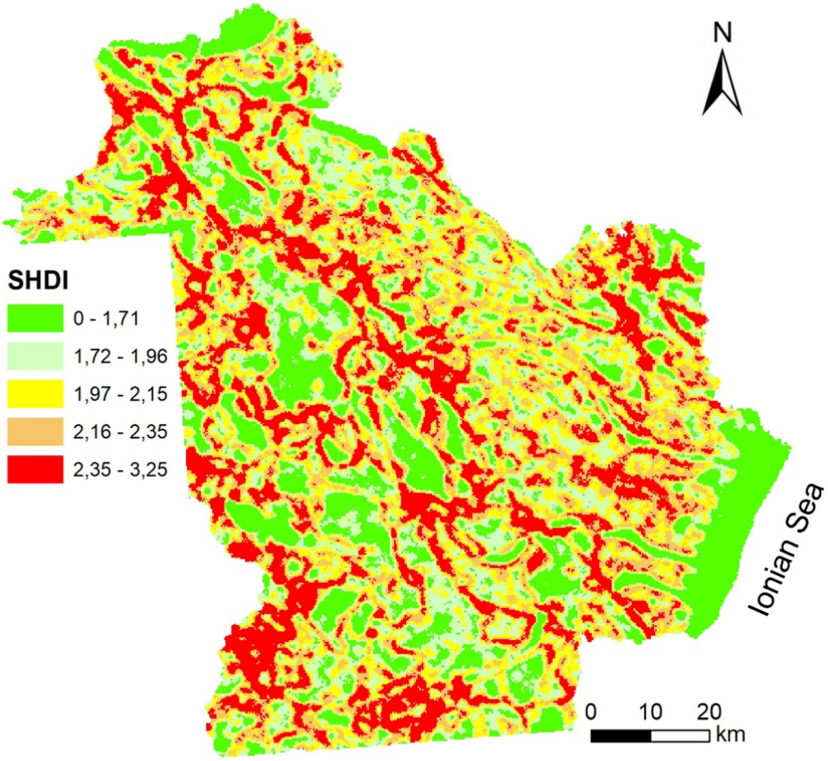


Fig. 5. Shannon's diversity index classification.

of the most important rivers; 3) where the landscape is dominated by the high-relief of morphostructural ridges made of shallow-water carbonates and deep-sea hard rocks. Lower values of geodiversity (0 > SHDI < 1.71) are observed mainly along the Ionian coastal belt (i.e. easternmost sectors of the study area).

The Shannon's Evenness index (SHEI) shows values between 0 and 1 (Fig. 6). Higher values (>2.35) of geodiversity are observed above all in areas characterized by a high variability of landscape shapes. This index also shows the lower values (<1.71) along the Ionian coast and in the central part of the map.

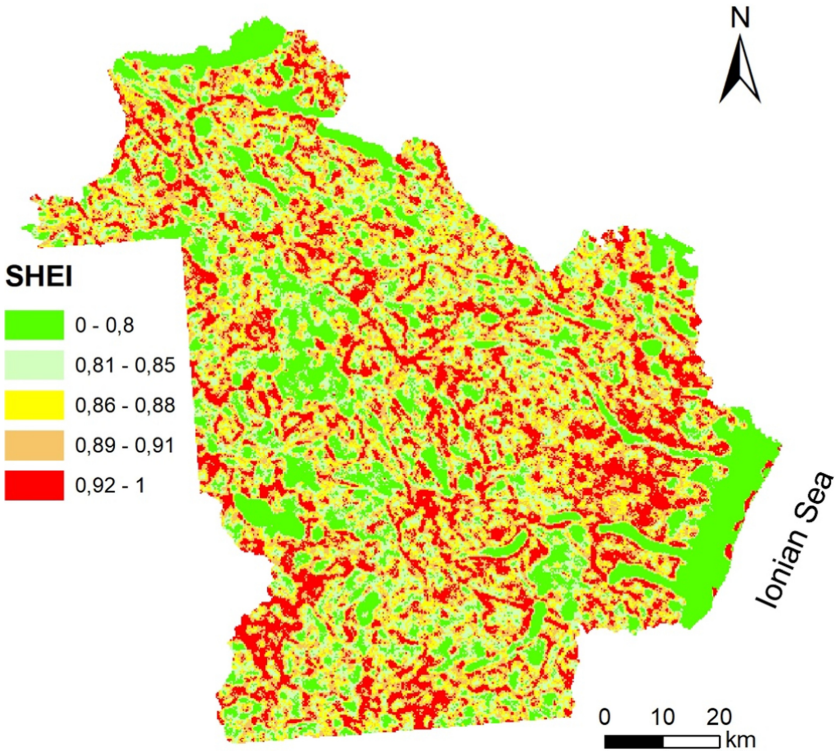


Fig. 6. Shannon's Evenness classification.

The Simpson index (SIDI) shows a distribution of geodiversity very similar to that shown by the SHDI index (Fig. 7). In fact, higher values of geodiversity are observed along the passage between the chain and the foredeep, on the border between the different hydrographic basins. Low values are observed along the Ionian coast.

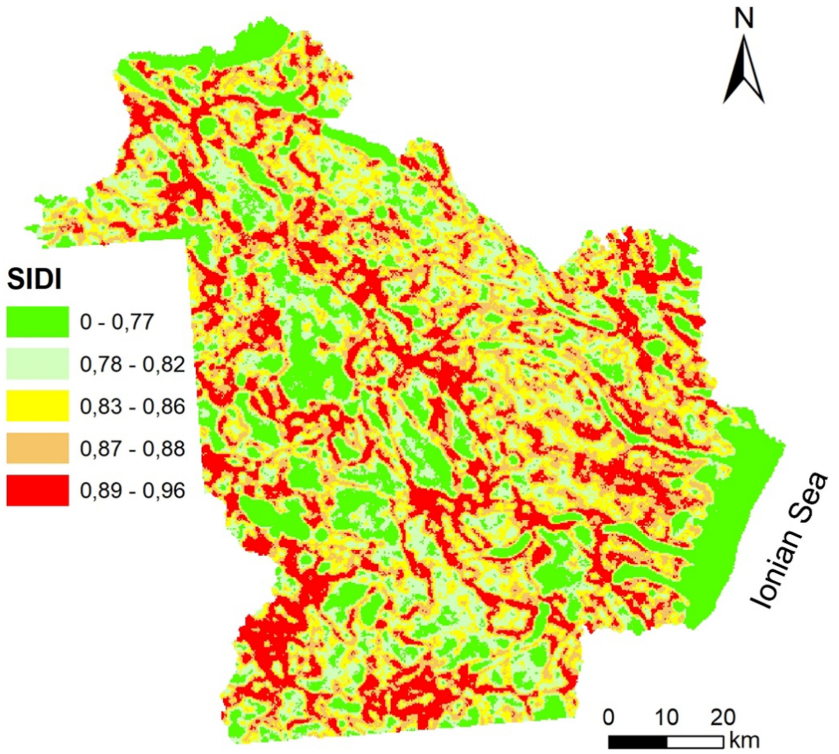


Fig. 7. Simpson's Diversity index classification.

For SHDI and SIDI index the high values of geodiversity depend on the passage from one lithology to another, this means that there is a high diversity of geomorphological forms for the same climate. Another factor of high geodiversity for all indices is the complexity of the geomorphological system, in fact the landscape sectors featured by well-hierarchized drainage networks correspond to sectors with higher values of geodiversity. Probably, in this case, the deep incision promoted the high fragmentation of the landscape a strong heterogeneity of the landform classes (Fig. 2). Instead, as all the indices show, low values of geodiversity are found along the Ionian coast, where characteristics of landscape shapes, climate, and geological information are almost the same. However, the geodiversity values shown by the three indices are similar in many cases, the SHDI and SIDI indices show almost the same results.

The results obtained allow us to identify the areas with different geodiversity and allow a macro subdivision into areas with different geological/geomorphological characteristics. In the future, the implementation of other parameters can allow the improvement of the final quality of the geodiversity maps.

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