ANALYSIS OF LANDSCAPE DIVERSITY USING A GEOGRAPHICAL INFORMATION SYSTEM

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ABSTRACT *- This article tests landscape classification in a natural diverse environment using a geographical information system. The first part briefly presents some results of a project that calculated the landscape diversity of Slovenia based on digital data on relief, rock, and vegetation. Areas with high landscape diversity are landscape hotspots, and areas with low landscape diversity are landscape coldspots. The second part of the paper presents landscape classification of an area that is partially marked as a landscape hotspot and partially as a landscape coldspot. Several geoinformation tools were used to determine landscape types in the selected test area, which lies along the contact between the Alpine plain and Alpine mountains about 30 km northwest of Ljubljana.*

Keywords: *geographical information systems, landscape classification, landscape diversity, Slovenia*

INTRODUCTION

Landscapes and landscape elements can be analyzed using various data and geoinformation tools, and based on the results specialists can carry out better and more effective spatial planning. Landscape analysis methods, which also include landscape classification, must be continuously further developed because the quantity and accuracy of data and the speed of computer algorithms are increasing rapidly.

This article describes two methods of analyzing landscapes using geoinformation tools for determining landscape heterogeneity and homogeneity.

The first part presents the quantitative method of determining Slovenia's landscape diversity, in which areas in Slovenia with the highest landscape diversity (landscape hotspots) and areas with the lowest landscape diversity (landscape coldspots) were identified. In the second part, a landscape classification of a test area with a diverse environment, which includes both landscape hotspots and coldspots, was carried out in terms of its physical geographical features. The classification was modeled and confirmed using the decision tree method (partly adopted from [1]).

FIRST PART: ANALYSIS OF SLOVENIA'S LANDSCAPE DIVERSITY

Very few countries, even considerably larger ones, can boast the landscape diversity found in Slovenia because the Alps, the Pannonian Basin, the Dinaric Alps, and the Mediterranean meet and interweave in this small corner of central Europe, as do Germanic, Hungarian, Slavic, and Romance cultural influences [2].

High landscape diversity is also confirmed by multiple Slovenian and European sources (see [3]). This section presents some results of the determination of differences within landscape-diverse Slovenia [4].

DATA AND METHODS USED FOR LANDSCAPE DIVERSITY ANALYSIS

In determining landscape diversity, we tested various data and various settings of geoinformation tools.

Three natural landscape elements are the most significant for the internal structure, function, and appearance of Slovenian landscapes: relief, rocks, and vegetation. They are so strongly linked with other natural landscape elements that a physical geographical regionalization or typology of appropriate quality can only be created by considering these three landscape elements [5].

As a base layer in a geographical information system, a 25 m digital elevation model (DEM) was used, which provides 32,436,693 square cells with a baseline of 25 m and an area of 6.25 ares.

Vector layers with 195 relief, 938 lithological, and 62 vegetation types were added. They were transformed from vector format to 25 m raster format because the remainder of the study used geoinformation tools for processing raster data layers. The number of types was generalized down to 7 relief, 15 lithological and 15 vegetation types.

First, we calculated the relief diversity. Using a moving window, we calculated the ratio between the number of relief types that occur within a radius of 1 km and the total number of relief types for each cell. We calculated the lithological and vegetation diversity in the same way.

Finally, we calculated the average of these three partial diversities. This is the landscape diversity. The minimum ratio is 3:37 or 0.0811 if only one relief type, one lithological type, and one vegetation type occur in a 1 km radius, and the maximum ratio is 37:37 or 1.0000 if all 7 relief types, 15 lithological types, and 15 vegetation types occur simultaneously in a 1 km radius [4].

For example, a landscape diversity of 0.2500 means that 25% of all 37 possible relief, lithological, and vegetation types occur in a 1 km radius.

SLOVENIA'S LANDSCAPE DIVERSITY

The most diverse areas lie along the contacts of major relief forms (plains, valleys, hills, and mountains), which are often related to changes in lithology and vegetation. Such contacts are usually also the major borders for other natural elements and processes.

The minimum value of the landscape diversity coefficient in Slovenia is 0.0811. These areas can be regarded as landscape coldspots and they cover 8.9% of Slovenia. The same percentage of the most diverse areas in Slovenia can be defined as hotspots. According to frequency distribution, we selected 8.3% of areas with the highest values (Figure 1; [4]).

Most landscape hotspots are located in Alpine Slovenia, encompassing more than two-thirds of their total area, and the fewest in Mediterranean Slovenia, corresponding to barely one-tenth of their total area. Most landscape coldspots are located in Dinaric Slovenia, encompassing almost half of their total area, and the fewest in Alpine Slovenia, corresponding to one-sixth of their total area [4].

SECOND PART: LANDSCAPE CLASSIFICATION OF TEST AREA

The alpine municipalities of Preddvor, Cerklje na Gorenjskem, and Šenčur were selected as the test area for the landscape classification using a multiple-modeling approach. This area is located approximately 30 km northwest of Ljubljana and covers 205.2 km² (Figure 1). Part of this area is classified as a landscape hotspot and part of it is classified as a landscape coldspot [4]. Thus, the area selected has a very heterogeneous landscape in some places and a very uniform one in others (Figure 2).

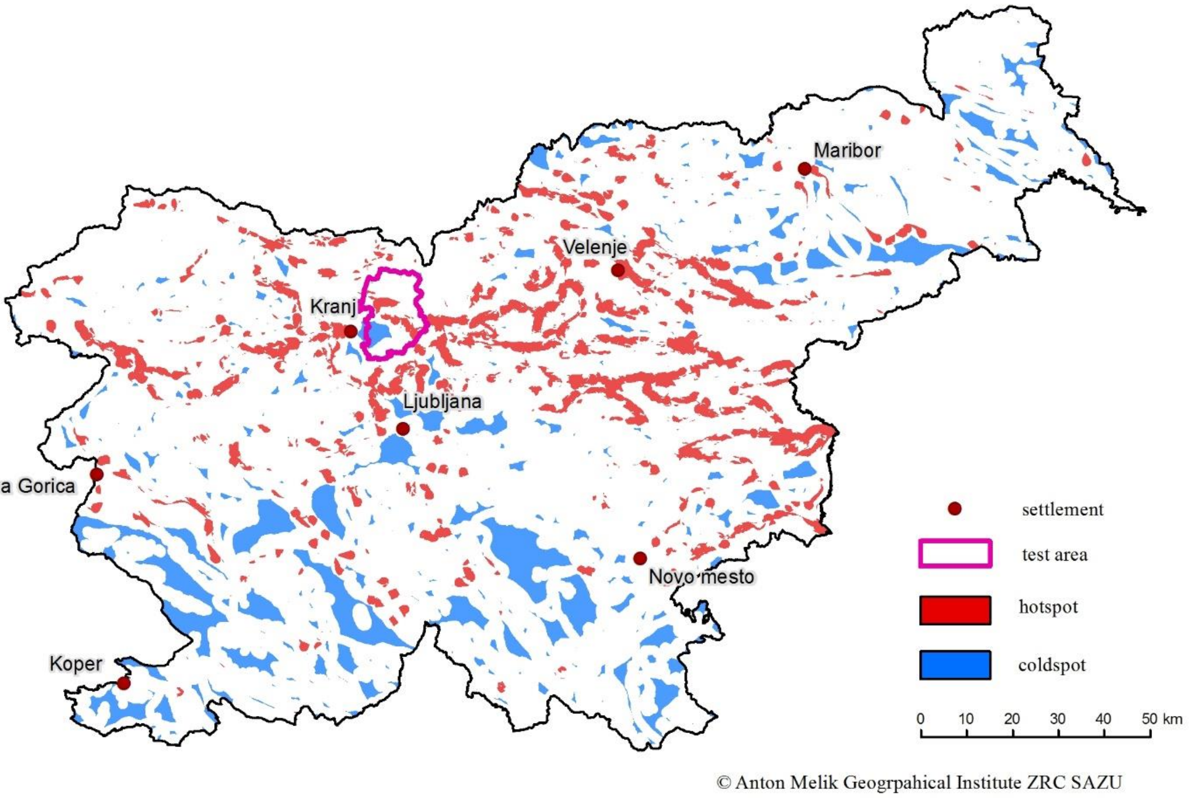

Fig. 1. Landscape hotspots and coldspots [4], and the location of the landscape classification test area.

Fig 2. Landscape classification test area. View from the southern, flat part (Kranj plain) towards the northern, mountainous part (Kamnik-Savinja Alps). Photo: Rok Ciglič

PREPARATION OF DATA FOR CLASSIFICATION

After the test area was selected, the following data layers of natural landscape elements were set:
– Rock types [6];
– Difference between the average air temperature in April and October;
– Permanent streams density (radius = 50, 100, 200, 250, and 500 m);
– Density of all streams (radius = 50, 100, 200, 250, and 500 m);
– Slope;
– Average annual solar radiation 1 [7];
– Average annual precipitation;
– Precipitation regime (Mediterranean index; adopted from Koppany & Unger 1992; cited in [8]);
– Curvature;
– Plan curvature;
– Profile curvature;
– Elevation;
– Density of depressions based on a 12.5 m DEM (radius = 100, 150, 200, 250, and 500 m);
– Density of depressions based on a 25 m DEM (radius = 100, 150, 200, 250, and 500 m);
– NDVI in August;
– "Red-edge" NDVI in August;
– Average annual solar radiation 2 [9, 10];
– Average annual air temperature;
– Amplitude between the average monthly air temperature of the coldest and the hottest month.

The data on the climate and streams were provided by the Slovenian Environment Agency and the European Environment Information and Observation Network, and the data for the digital terrain model were obtained from the Slovenian Surveying and Mapping Authority. The satellite images were prepared by National Aeronautics and Space Administration. All of the data layers are numerical; only the rock type layer is nominal. The resolution of the raster data was 12.5 m, of the satellite images 30 m, and of the climate data 1 km. Other data were obtained in vector format.

The data were first analyzed by calculating the **intercorrelation** and **coefficient of variation** on systematically designed square areas of various sizes [1]. This showed which data layers were correlated too strongly (and could therefore be eliminated from the selection of classification data) and how individual data varied in space (and thus how useful they were for classification) at various spatial levels (scales). At the same time, it could be established which data create noise (i.e., their spatial variability is too high at all levels).

Due to a large quantity of data (the number of cells was 1,313,773), a **segmentation** was first carried out on the basis of the data layers that have good spatial resolution and are variable at a large scale. The raster format was thus converted into a vector format and cells were replaced by segments (polygons) as the basic units. This reduced the quantity of data (14,579 segments) with a minimal loss of detail.

The following three data layers were selected for segmentation: density of permanent streams (50 m radius), NDVI, and curvature. They all have the highest coefficients of variation at a large scale, which means that other data layers are less variable and could not be used to define the basic segments. All three data layers selected have extremely low correlation levels (Table 1). Before the segmentation, the data layer values were transferred onto a 0–255 scale, and the segmentation was carried out with Idrisi Selva [11] software, which uses a combination of two algorithms: watershed segmentation and region growing [12]. The following settings were used: equal layer weight (0.3333), window width: 3, weight mean factor: 0.5, and weight variance factor: 0.5.

Table 1: Correlation between the data layers used for segmentation (all values of Pearson's correlation coefficient are statistically significant at 0.001 using a two-tailed test).

	Total curvature	NDVI	Perennial stream density
Total curvature	1	0.009	−0.118
NDVI		1	0.040
Perennial stream density			1

After the segmentation, every segment (polygon) was ascribed an average, minimum value, maximum value, and the standard deviation of each numerical raster data layer. In the case of nominal data (rock type), the most frequent value and the number of different values were ascribed to the segments. In addition, the correlation of attributes was analyzed based on segments. The correlations established were similar to those determined in the raster analysis.

CLASSIFICATION METHODOLOGY

Based on the analyses described above, a decision was made to carry out the landscape classification of the test area using the decision tree method [13, 14] because it makes it possible to include both nominal data (e.g., rock type) and numerical data (e.g., slope). This fact was important because the database used included both types of data. In addition, this made it possible to include several data layers that can either have a non-normal distribution or are correlated with one another.

DEFINITION OF LANDSCAPE TYPES

Relief, rock, and climate are relatively constant factors that influence those that are more changing, such as vegetation and land use, which show the external image of a landscape. A system must be based on causes because a landscape ecosystem can only be understood if its origin is known [15, 16]. Because the test area is small, its climate practically does not change in horizontal direction. However, it does change vertically (i.e., with elevation). Before the test area was **classified** into **landscape types**, landscape elements, especially the less variable ones—such as rocks, slope, and elevation as a climate modifier (Tables 2, 3, and 4), which have an important impact on other landscape elements—were inspected in the field to define the main **combinations of potential landscape types**. Based on the combinations of the main landscape element types or classes (Tables 2, 3, and 4) and fieldwork, the following eight landscape types were defined:

- 1 Conglomerate terraces
- 2 Gravel terraces
- 3 Non-carbonate low hills
- 4 Carbonate hills
- 5 Carbonate plateaus
- 6 Mountains
- 7 Non-carbonate hills
- 8 Mountain valleys

Table 2: Types of rock in the test area.

Rock	**ID**
Limestone and dolomite	R1
Limestone and dolomite with other rock	R2
Conglomerate	R3
Metamorphic and igneous rock with tuff	R4
Unconsolidated rock	R5
Sandstone and marl	R6
Sandstone, marl, conglomerate, and breccia	R7

Table 3: Main slope types in the test area.

Slope	**ID**
Flatland	I1
Slope	I2

Table 4: Main elevation classes in the test area.

Elevation as a climate modifier	**ID**
1,800–2,000 m (above the tree line)	E1
1,000–1,800 m (tree line)	E2
480–1,000 m	E3
< 480 m (elevation of the largest flatland)	E4

LANDSCAPE CLASSIFICATION FOR THE ENTIRE TEST AREA (RESULTS)

Several segments (polygons) were defined for every landscape type; these segments became the **learning sample** for developing the **classification rule** for the decision tree method. Modeling was carried with a decision tree that uses the CRT algorithm [14]. Data on the average density of permanent streams (radius = 100 and 50 m), average density of all streams (radius = 100 m), average slope, average elevation, average depression density (radius = 200 m; 12.5 m DEM), and the most common rock type were used. Pruning was also used (SE = 1); the maximum allowed size of the tree was 10 levels, the minimum number of segments in child nodes was 30, and the minimum number of segments in parent nodes was 100. The Gini coefficient was used as an impurity measure.

All of the segments in the test area were classified following the rule above. The resulting classification was checked and manually adjusted in places. The greatest adjustment was made to the test area's south, where an area that had first been classified under mountain valleys was reclassified under gravel terraces. In the central part of the test area, the area of carbonate plateaus and gravel terraces was increased.

In the last stage, the adjusted classification, in which all segments were taken into account, was used to develop a new classification rule, based on which a new classification was made for the entire test area (Figure 3). This procedure could have been repeated several times to further optimize the classification but, considering that the purpose of this article is to merely demonstrate or simulate the landscape classification method presented, the procedure was terminated (Table 5, Figure 4).

The main purpose is thus to use the suitable landscape variables (data layers) to determine the quality of an existing landscape classification, and to use selected mathematical rules to confirm and improve it through multiple modeling based on a learning samples (Table 5).

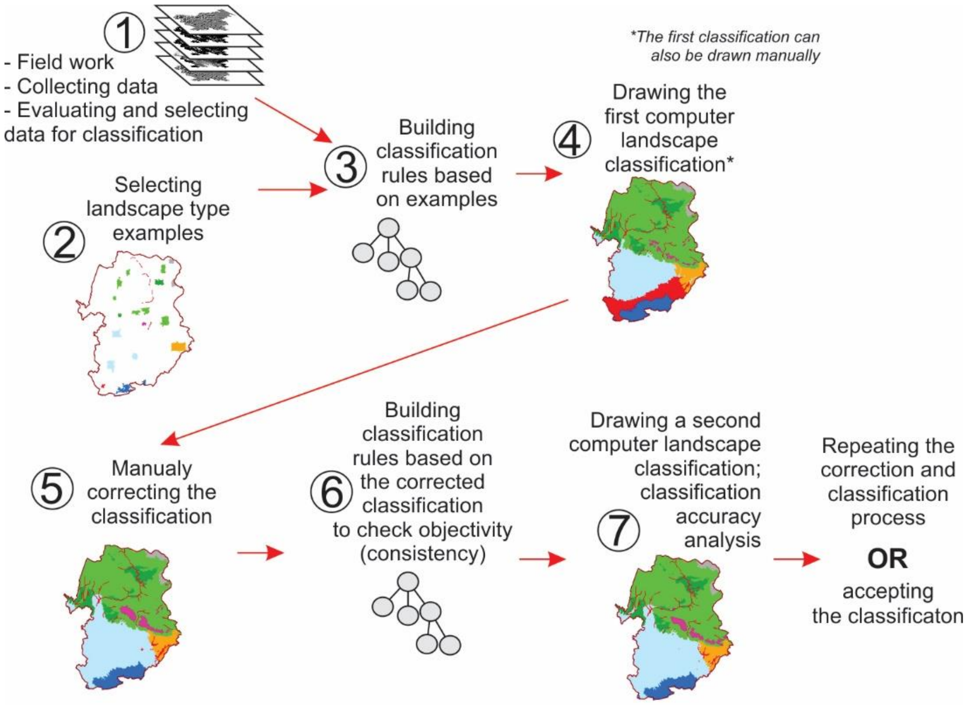

Fig. 3. Landscape classification procedure schema.

Table 5: Overview of the success rate of modeling the classifications produced.

	Learning sample includes all segments	Learning sample includes 80% of the segments	
	Success rate of classifying all segments	Success rate of classifying learning segments	Success rate of classifying test segments
Success rate of modeling the first computer classification (Figure 3, Point 4; Figure 4A)	99.1	98.9	98.8
Success rate of modeling the manually adjusted computer classification (Figure 3, Point 5; Figure 4B)	97.7	97.4	97.0
Success rate of modeling the computer-modeled manually adjusted computer classification (Figure 3, Point 7; Figure 4C)	99.5	99.3	99.0

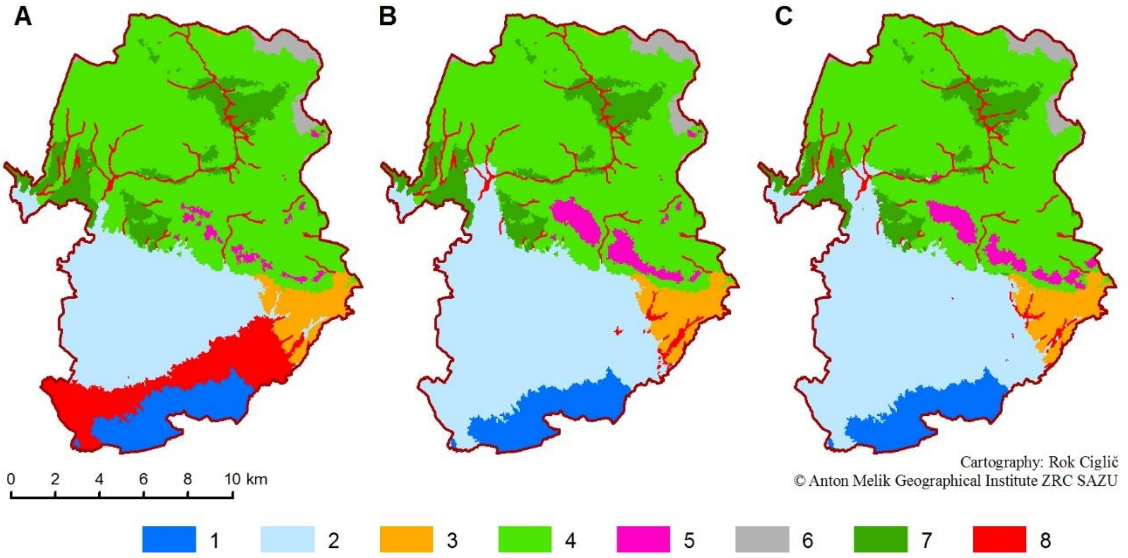

Fig. 4. Graph showing landscape classifications by individual stage (A, B, C). Landscape types included: conglomerate terraces (1), gravel terraces (2), non-carbonate low hills (3), carbonate hills (4), carbonate plateaus (5), mountains (6), non-carbonate hills (7), and mountain valleys (8).

Table 6: Average data layer values by landscape type.

Landscape type	**Permanent stream density (m/m²)**	**Density of all streams (m/m²)**	**No. of depressions/m²**	**Slope (°)**
3 Non-carbonate low hills	0.00078974	0.00205396	0.00000120	15.4
5 Carbonate plateaus	0.00004104	0.00009908	0.00002618	12.8
2 Gravel terraces	0.00066349	0.00077508	0.00000607	1.3
1 Conglomerate terraces	0.00000229	0.00006655	0.00005479	0.9
6 Mountains	0.00000000	0.00003103	0.00000176	37.3
7 Non-carbonate hills	0.00093494	0.00150055	0.00000189	17.2
4 Carbonate hills	0.00010271	0.00076017	0.00000057	29.0
8 Mountain valleys	0.01081585	0.01116048	0.00000033	14.3
Landscape type	**Solar radiation (MJ/m²)**	**Air temperature in January (°C)**	**Air temperature in July (°C)**	**Elevation (m)**
3 Non-carbonate low hills	4,204.8	−0.9	18.4	453.4
5 Carbonate plateaus	4,133.8	−1.6	17.2	678.4
2 Gravel terraces	4,125.4	−0.8	18.9	394.5
1 Conglomerate terraces	4,112.0	−0.6	19.3	361.4
6 Mountains	3,989.3	−4.7	9.5	2,095.2
7 Non-carbonate hills	3,924.3	−1.8	16.9	660.8
4 Carbonate hills	3,923.5	−2.6	14.9	1,029.4
8 Mountain valleys	3,834.0	−1.7	17.1	573.3

Most of the southern half of the test area is classified under gravel terraces; only the extreme southern edge is classified under conglomerate terraces. Most of the northern half of the test area is classified under carbonate hills, with carbonate plateaus, mountains, and non-carbonate hills in between. The eastern central part features many non-carbonate low hills. Mountain valleys can be found in the northern half and the central eastern part of the test area.

The average values of natural elements (Table 6) show that values vary between types and match the individual types' properties. For example, the density of streams is the highest in the mountain valleys and the smallest in the mountains and on conglomerate terraces and carbonate plateaus.

CONCLUSION

Geographical information systems provide various ways to analyze landscapes. This article uses tools and spatial data to determine the degree of landscape diversity for all of Slovenia. Following this, a landscape classification is also produced for a test area covering three Slovenian municipalities with various degrees of landscape diversity, providing the basic information on the area's physical geographical features.

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