A TYPOLOGY OF NATURAL LANDSCAPES OF CENTRAL EUROPE

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ABSTRACT

Landscape classification of Central Europe was carried out in order to define the spatial framework of environmentally homogeneous typological units. The output of such a classification would be used for further assessment of ecosystem services within the focus region. Classification was based on the cluster analysis of principal components, derived from a set of abiotic data – climatic and terrain variables and a soil database. Seven specific landscape types were defined within Central Europe. Regional distribution and environmental characteristics of particular units are described.

Keywords: landscape classification, principal component analysis, cluster analysis

1. Introduction

Landscape classification is one of the traditional topics of landscape ecological research. Over the last decades, European landscapes have been endangered by environmental changes and globalization, which can lead to their unification and loss of specific character (Mücher et al. 2010). As pointed out in the European Landscape Convention, diversity and richness of environment originating from different natural and cultural factors belong to European heritage (Council of Europe 2000). This convention appeals to protect all valuable landscapes, no matter if they are natural or strongly influenced by humans. Thus delimitation of landscape types has become more urgent. Typologies are used for identification of specific and valuable areas, for further evaluation of state and changes, or as a background for consequent studies of other characteristics. The practical utilization of typologies is also seen in miscellaneous policies and regional planning (Bastian et al. 2000).

Methods of classification have been progressively evolving in time. Holistic typologies were typically based on general perception of landscapes. Expert statement typologies set intuitive delimitation of classes based on an author's experience. They can be based on objective input data, but boundaries are created subjectively. Bunce et al. (2006) warns that these approaches often ignore areas hard to assign to some class. An indisputable benefit of these studies is that they include non-measurable or subjective variables, which are especially crucial for identification of cultural landscapes.

Today's studies tend to create objective classifications based on statistical methods with usage of GIS tools, so-called quantitative typologies. These techniques are supported by broadly available free digital datasets that can be used as inputs in classification. Thematic layers are mostly created within EU initiatives. Quantitative typologies allow authors to repeat procedures including the latest or updated data. An objective classification is also the only way how to objectively divide variables changing in gradients (for example climate variables) and get really comparable spatial units. Hazeu et al. (2011) unifie terminology, claiming that a classification of gradients is typically called a stratification. The term typology describes classification of well-marked units with specific character. The three most common procedures of quantitative typologies are: (1) the spatial overlay of thematic layers (Hazeu et al. 2006; Metzger et al. 2010), (2) the multispectral segmentation (Mücher et al. 2010), or (3) the cluster analysis (Kolejka & Miklaš 1986; Metzger et al. 2005; Chuman & Romportl 2010). All these methods can also be combined in complex multi-level typology (van Eetvelde & Antrop 2009; Romportl et al. 2013). The classification results in a map that synthetizes all input thematic layers.

National landcape typologies in Europe are quite common (eg. Bunce et al. 1996; Lioubimtseva & Defourny 1999; Chuman & Romportl 2010; Kolejka 2010; Kolejka et al. 2010; van Eetvelde & Antrop 2009). It can be said that most of the states have their national classifications. There have also been some attempts to classify the whole area of Europe. These studies (Metzger et al. 2005; Mücher et al. 2003, 2010) were developed mainly after ratifying of the European Landscape Convention in 2000, which also highlights an importance of landscape typology and requires its production.

1.1 International Landscape Typologies in Europe

The first international landscape typology was the World Map of Present Day Landscapes, which was co-ordinated for the United Nations Environmental

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Programme (UNEP) by E.V. Milanova at Moscow State University. This work is a synthesis of two maps: *Geographical Belts and Zonal Types of Landscapes of the World* (1988) and *Land Use Types of the World* (1986), both in scale 1 : 50,000,000, which together delineate more than 150 types. Satellite images, regional thematic maps and field surveys were used as data inputs (Wascher ed. 2009). According to Wascher ed. (2009), these maps are all coarse in scale, thereby causing a number of inaccuracies. Thus they rather are not being used these days.

Another classification named *Pan-European Landscapes*, covering the whole Europe in scale 1 : 25,000,000, was developed by J. H. Meeus for the Dobříš Assessment in 1995. This typology tries to create a framework for assessing relationship between natural and anthropogenic factors in the environment (Meeus, 1995). The author took into account six main criteria including climate, geomorphology, sustainability of management, wilderness, genuineness and also the most important variable, which was defined as "a scenic quality and visual characteristic of region" and reviewed in terms "enclosure or openness of the landscape". The study identifies thirty main types of rural landscape, but it excludes urban, industrial and mining areas, or intertidal flats, that according to Meeus's opinion don't represent European natural and cultural heritage (Lipský & Romportl 2007). Although his work is quite general and subjective, the question of classifying and assessing cultural landscapes is still actual (Wascher ed. 2005).

In the same time as Meuss' work, different approaches were used to develop other examples of supranational landscape classifications of Central Europe (Richling et al. 1996a,b).

Two contemporary landscape classifications were developed as part of ELCAI project (the European Landscape Character Assessment Initiative) (Wascher ed. 2005). One of the goals of this project was to create two independent typologies of natural and cultural environment. Both works attempt to use objective procedures, transparent methodology, and future implementation in European and national policies (Mücher et al. 2003).

The Environmental Stratification of Europe, also called the Climatic Stratification of Europe, was created by M. Metzger and his team in 2005. The resolution of this stratification is 1 km^2. This classification is principally based only on climatic data, which can generally express the biophysical conditions in Europe. These are climate continentality, mean monthly values of minimum and maximum temperature, precipitation, and percentage of sunshine for four or five representative months of the year. Further added data are latitude, slope and altitude derived from digital elevation model. The first run of cluster analysis showed a strong heterogeneity of landscapes in Southern Europe, which led to division of Europe into two parts analyzed separately in order to gain spatially comparable units (Metzger et al. 2005). This resulted in the identification of six main environmental regions and 84 strata called *EnS*. Until these days, the stratification has been used in a number of other typologies and studies (Hazeu et al. 2006; Mücher et al. 2010; Metzger et al. 2010; Van Eupen et al. 2012).

The European Landscape Classification (LANMAP) brings a complex typology of cultural landscapes. Mücher et al. (2010) present the newest version with improved methodology. As appropriate input data in this study were considered climate, altitude, parent material, and land cover/land use. Last mentioned variable is the only representative of the anthropogenic influence in the meaning of cultural structures in the environment. Climate data layer was obtained from Climatic Stratification of Europe in combination with Biogeographical Regions Map of Europe (Roekaerts 2002). Object-based image segmentation of thematic layers identified 350 landscape types at the lowest level of classification. LANMAP was later used for developing the Spatial Regional Reference Framework (SRRF) and for the analysis of landcover changes (Hazeu et al. 2011).

An overview of recent typologies in Europe wouldn't be complete without mentioning some more thematicaly oriented ones such as the Biogeographical Regions Map of Europe (Roekaerts 2002), the Spatial Regional Reference Framework (Renetzeder 2002 in Hazeu et al. 2011), the Agri-Environmental Zonation (Hazeu et al. 2006) or the Rural Typology (Van Eupen et al. 2012).

2. Materials and methods

Creating landscape typology consists of three steps, (1) selection of variables, (2) reducing number of variables and cluster analysis, and (3) a description of identified landscape types.

2.1 Study area and objectives

The Central Europe is the area of study represented by the states of Germany, Switzerland, Austria, Poland, Slovakia and the Czech Republic. Biophysical conditions in this area are very heterogeneous and so is the cultural tradition. We try to classify a natural landscape in order to identify relatively homogeneous units with the same environmental potential. This background can be used for consequent studies of state and development of landscape types under different socio-economical conditions. In case of Central Europe, it is typically diversity of political development and regional planning in states' history. We also want to build our own typology using modern objective methods and widely available free datasets. Such a new typology should be available in high resolution.

2.2 Input datasets

When selecting the most adequate input layers, the well-known functional hierarchy of landscape components based on a model by Klijn and Udo de Haes (1994)

Tab. 1 Input datasets, its resolution and sources.

Layer	Format	Resolution	Database	Source
mean temperature	raster	1 km^2	WorldClim v1.4	worldclim.org
mean precipitation	raster	1 km^2	WorldClim v1.4	worldclim.org
altitude	raster	1 km^2	GTOPO 30	eros.usgs.gov
soil coverage	vector	1 : 1,000,000	European Soil Database v2.0, SGDBE v4beta	eurosoils.jrc.ec.europa.eu

was considered. Abiotic components are followed by dependent biotic components and cultural structures stand on the top of this hierarchy. Our task was to create classification of natural landscape, which would exclude all layers reflecting some anthropogenic activity such as land cover or land use. We also intended to use broadly available and free datasets. These two conditions, eventually, strongly limited our possibilities.

For purposes of classification climatic variables from WorldClim v1.4 database, terrain variables from digital elevation model GTOPO30, and soil coverage data from Soil Geographical Database of Eurasia (SGDBE) v4beta were used. SGDBE is part of the European Soil Database v2.0 (Table 1).

Three main climatic variables were derived from the database. First of all, mean annual temperature was derived from database of particular mean monthly temperatures. The annual precipitation was deduced in the same way. The third climatic variable is an amplitude of temperatures as a difference between mean temperature of July and January. All layers were expressed in a raster format as well as the digital elevation model (Figure 1).

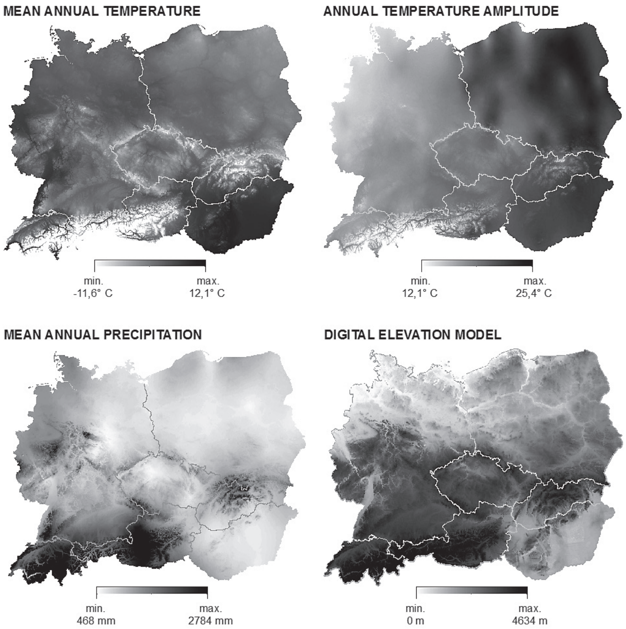

Fig. 1 Input raster datasets.

Soils were represented in a vector dataset (Figure 2). The soil coverage in SGDBE is classified by the Soil Typological Units (STU), which are grouped into the Soil Mapping Units (SMU) due to forming soil associations. A scale of geometrical dataset is 1 : 1,000,000, which makes STUs too detailed for delimitation, therefore SMUs were set as an effective units. Each SMU is assigned to World Reference Base (WRB) reference soil group. Thirty reference soil groups and six more categories (describing units without soil coverage like glacier, rock outcrop or town, and eventually category of unclassified units) are used in SGDBE. Twenty three of these categories appeared in our study area. This is a high number of variables for the cluster analysis. That's why categories were merged into ten groups according to description of their nature by Němeček et al. (2011). Non-soil classes were also reduced in four classes. An overview of the groups and the original classes is in Table 2.

Through all generalization we did in step above, there still remained considerable areas of unclassified units in Switzerland. A comparison with satellite imagery has shown that these areas belong to four classes of SMUs and represent intravilan, glacier, or rock outcrops. These findings pushed us to modify the database. SMUs 2, 5, 410018 a 410019 were added to the proper groups manually.

Tab. 2. Original WRB categories and generalized groups of soils.

Group	**P1**	**P2**	**P3**	**P4**	**P5**	**P6**	**P7**
WRB category in SGDBE	fluvisol	arenosol, leptosol, regosol	vertisol	chernozem, phaeozem	cambisol	albeluvisol, luvisol	gleysol, planosol
Group	**P8**	**P9**	**P10**	**P11**	**P12**	**P13**	**P14**
WRB category in SGDBE	solonchak, solonetz	histosol	marsh, unclassified	podzosols	glacier, rock outcrops	water body	town, soil disturbed by man

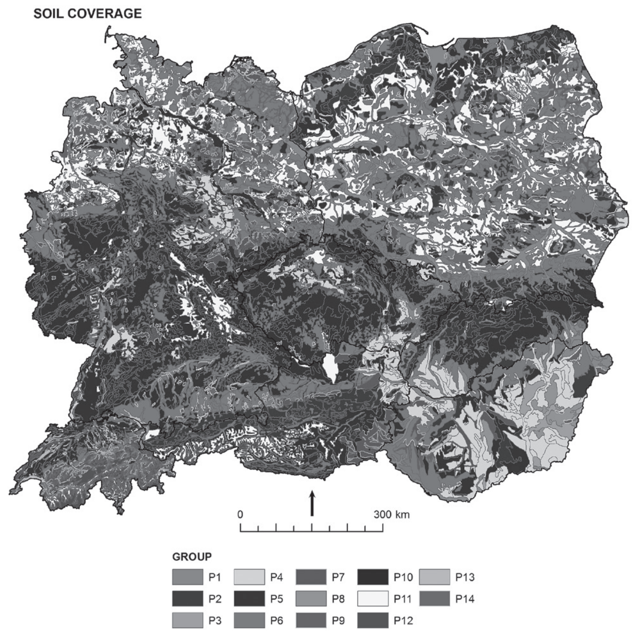

Fig. 2 Vector database of soils derived from SGDBE.

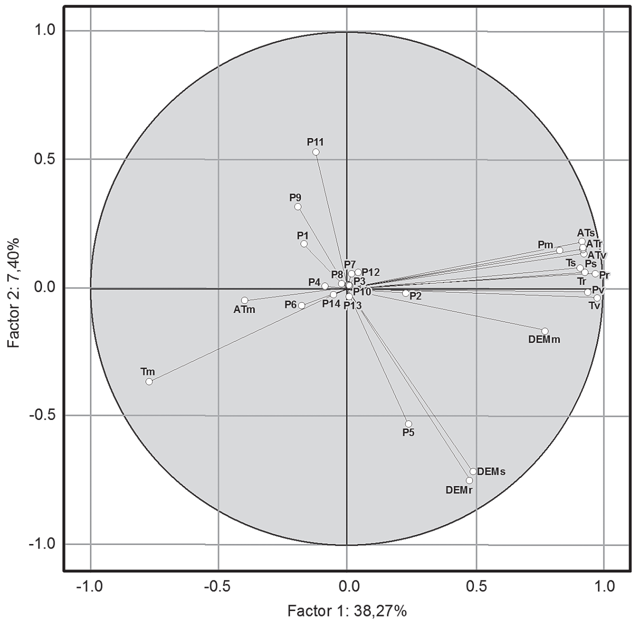

Fig. 3 Principal component analysis – projection of variables.

2.3 Classification

The input data were transformed into grid cells for purpose of analysis. This is a very common method to simplify data overlay and avoid slivers (van Eetvelde & Antrop 2009). A reference EEA grid with size of one cell 10 × 10 km was used. Resolution of input datasets didn't provide a proper information in small cells at the border of studied area. That's why cells under 1 km² and all the islands were excluded from the classification. Vector input datasets were expressed as a proportional area, which covers each category of layer in each cell. Raster datasets were transformed by the tool Zonal Statistics in ArcGIS 10.1 as basic statistical characteristics like mean, minimum, maximum, and first and third quartile of values in each grid cell.

Classification itself was the next stage. All processes were done in software Statistica 10. At first, number of standardized variables was reduced by Principal Component Analysis (PCA) that explained 67% of data variability. As the most correlated were detected climatic variables with exception of mean temperature and amplitude of temperatures (Figure 3). Results of PCA were used as an input in non-hierarchical cluster analysis K-means. Analysis divides all units into required number of clusters, and moves the objects to achieve the greatest homogeneity inside clusters and heterogeneity between them (Lepš & Šmilauer 2000). The final number of clusters is defined by user. In this case seven clusters were identified.

3. Results

Cluster analysis identified seven clusters (Figure 4). A short description of each cluster – natural landscape type – follows. One must be aware of high level of generalization, which was done at the first step for each grid cell and secondly for the whole landscape type. All of the values can be very variable within one landscape. The temperature and precipitation characteristic for each landscape are average values per year.

Type 1: The landscape of uplands and highlands of Central Europe. Average elevation is 400 metres above sea level. Temperature is around 7 °C and total received precipitation is 720 mm in average per year. Climate is relatively moderate. Cambisols represent the typical soil type. This landscape covers central Germany, almost

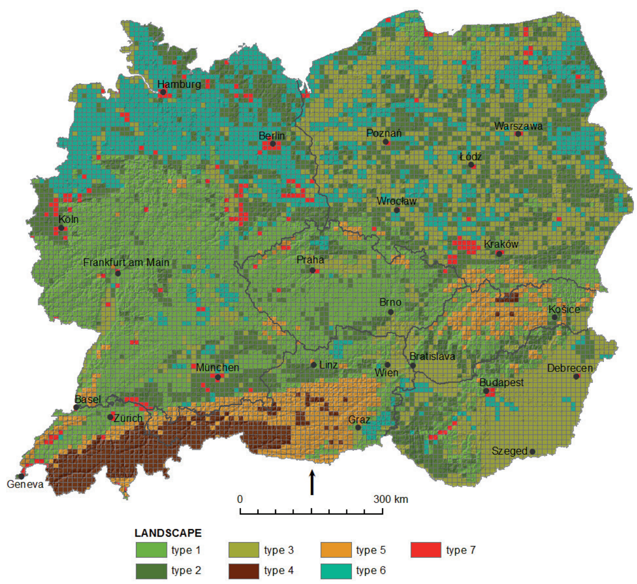

Fig. 4 Landscape typology of Central Europe – seven types of natural landscape.

Tab. 3 Statistical characteristics of raster datasets used in PCA.

Layer	Statistical characteristic of values in each field	Abbrev. in PCA projection
DEM	mean	DEMm
	standard deviation	DEMs
	range	DEMr
Amplitude of temperatures	mean	ATm
	standard deviation	ATs
	variation	ATv
	range	ATr
Temperature	mean	Tm
	standard deviation	Ts
	variation	Tv
	range	Tr
Precipitation	mean	Pm
	standard deviation	Ps
	variation	Pr
	range	Pv

whole area of the Czech Republic, and also lower parts of Switzerland, Austria and Slovakia.

Type 2: The average temperature in these piedmontan and hilly landscapes is 8 °C and annual received precipitations are around 600 mm. The mean elevation is 200 m and climate is relatively continental. Luvisols and albeluvisols are typical soils here. There are only small enclaves of this landscape spread in Central Europe, for example along the Danube, or the Rhine.

Type 3: The third landscape type of lowland landscapes is characterized by the lowest elevations above 100 metres above sea level. The amplitude of temperatures is the highest among all other types of landscapes, which shows a high continentality level. The amount of precipitation is, on the other hand, low – around 600 mm per year – and the average temperature is 8 °C. Chernozems and phaeozems, fluvisols, and solonchak or slanetz are typical soils for this type. These landscapes are situated mostly in the eastern part of studied area, in Hungary and Poland and West-Pannonian basin.

Type 4: The landscape of the highest mountain ranges in studied area. The mean elevation is 1800 metres, although a maximum is more than 3000 m. The amplitude of temperatures is typically low, which corresponds with high elevations. The mean annual temperature is around 2 °C and the precipitation exceeds 1320 mm per year. Only primitive soils occur here, like leptosols, perhaps even podzosols, but this landscape is dominantly covered by glaciers and rock outcrops. This landscape is typical for Alps in Switzerland and Austria and highest peaks of Tatras in Slovakia.

Type 5: This natural landscape is situated at average elevations of 900 m with vertically dissected terrain. The mean annual temperature is around 5 °C and received precipitation 1080 mm per year with high variability. Soils are either poorly developed or represented by cambisols. It's the second landscape of highlands in this typology, but it differs from the former in soil cover and vegetation. Harz, Jura, Schwarzwald mountains, and also almost the whole area of Slovakia and tops of mountains in the Czech Republic (like Krkonoše, or Hrubý Jeseník) belong to this category.

Type 6: The landscape of flat lowlands with mean altitude less than 100 metres above sea level with the average temperature around 8 °C and precipitation around 600 mm per year. Climate is moderate. Podzols and histosols, but also gleysols and planosols are typical soils of this landscape type. Regionally, this landscape occurs, for example, in the North German lowlands or Austrian Waldviertel.

Type 7: The last landscape type is characterized by the highest mean temperature, around 9 °C. The monthly receive of precipitation is about 600 mm per year, and elevations are very variable. Degradated soils, water bodies, and intravilans are being typical. It corresponds with the landscapes of industrial and mining areas, agglomerations and lakes. In details, capitals of states, lakes in Switzerland, or Balaton in Hungary, conurbations in Upper Silesia in Poland, or Rhine and Ruhr area in Germany can be mentioned.

4. Discussion and conlusion

Seven landscape types identified in cluster analysis of K-means have unique characteristics and correspond with main environmental gradients in studied area. The validation of typology in comparison with other existing classifications (Mücher et al. 2010, Kindler in Wascher ed. 2009) is a common procedure. Nevertheless, this step was not done in this case because Pan-European studies are rather too coarse.

Although actual objective method was used, there are a few disputable steps. First, it is a selection of input layers. The classification of natural environment is based on climatic, topographic, and soil coverage data. Unfortunately, there were no more proper datasets available, which is the reason why we didn't include, for example, geological layer, and therefore soil data has to be considered as an adequate substitute. Data availability followed by their subjective selection (Chuman & Romportl 2010) is typically being the main limitation in classifications. We are able to say that in this case there was no subjective selection because there were no more data available. On the other hand an absence of particular data doesn't mean that typology cannot be proceed. Haines-Young at al. (1992) classified landscapes of Wales using only satellite image and derived land cover mosaics. In any case, we suggest that for such a large area as in this study various detailed layers are needed.

The most controversial step is the manual intervention into the soil database SGDBE v4beta in which we had to change some categories after comparing it with satellite image. However, it was necessary because of an inaccuracy in the database. These errors can be explained in methodology of SGDBE database at scale 1 : 1,000,000. As said in database metadata, "precision of the variables is weak" due to the estimation of soils over the large areas by expert knowledge instead of measuring local soil samples. We also put together WRB reference soil groups into the bigger groups according to their natural properties (Němeček at al. 2011). This procedure should reduce number of variables and eliminate the differences between national soil systems transformed into WRB categories in SGDBE. For example, Zádorová and Penížek (2011), who focus on harmonisation of Czech national soil system and the World Reference Base, describe in detail problems with transformation. Other European classifications, like Metzger et al. (2005), didn't include soil coverage into the Climatic Stratification of Europe because of the same problems we describe above. Mücher et al. (2010) generalized the European Soil Database and FAO Soil Map of the World (both representing parent material in LANMAP) into three classes, which probably eliminated all errors.

Cluster analysis is an objective method, but the number of clusters is set manually. This subjective step is unavoidable and has to be done in every cluster analysis (Bunce et al. 1996). However, different numbers can yield different results. According to Lepš and Šmilauer (2000), we have also tried to create versions with 5 and 6 clusters, but the results tend to be too coarse, hence we eventually decided to use classification identifying 7 clusters. Higher number of classes often leads to definition of unique landscape phenomenon rather than landscape types. Moreover, interpretation of more clusters can be problematic.

The landscape type number 7 corresponds with areas strongly influenced by man and areas with water bodies. This landscape was identified due to the dominantly absent soil cover. Although the goal of this study was to classify landscapes of natural environment, we decided to keep this class in typology. For example Mücher et al. (2010) excluded water bodies, agglomeration, and intertidal flat with a mask based on CORINE Land Cover layer. In this step he also solved the problem of missing soil data for these areas. In our case it wasn't necessary because the soil layer was available in accurate resolution.

The benefit of our work is in relatively high resolution of seven classes in grid of 100 km^2 which haven't been developed for this area of interest before. This approach allows us to respect regional specifics although we keep in mind there is still high level of generalization. We see an application of our work in future studies evaluating state and development of landscapes. It can be useful for strategic random sampling, evaluation of landscape fragmentation, or environment evaluation with ecosystems services approach.

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RESUMÉ

Typologie přírodních krajin střední Evropy

Krajina střední Evropy vykazuje vysokou heterogenitu přírodních podmínek, které determinují intenzitu a charakter jejího využití. Cílem předloženého příspěvku bylo zpracovat typologii krajiny podle přírodních podmínek prostředí tak, aby zachycovala hlavní environmentální gradienty v zájmovém regionu. Výsledkem klasifikace krajiny podle přírodních podmínek jsou opakovatelné homogenní jednotky, které představují jednotný prostorový rámec pro potenciální hodnocení stavu a dynamiky krajinných procesů. Metodický postup typologie krajiny je založen na několika návazných krocích: (1) výběr, předzpracování a standardizace vstupních dat charakterizujících abiotické poměry regionu; (2) dekorelace a snížení počtu vstupních proměnných pomocí analýzy hlavních komponent; (3) vlastní klasifikace krajinných typů s využitím klastrové analýzy.

Jako vstupní proměnné byly využity proměnné popisující klimatické poměry (průměrná roční teplota, amplituda teplot, průměrné roční srážky) odvozené z databáze WorldClim, dále nadmořská výška (databáze GTOPO30) a nakonec vrstva půdního pokryvu odvozená z databáze SGDBE.

Do klastrové analýzy vstupovaly již jen první tři komponenty z analýzy PCA, vysvětlující celkem 67 % variability původního datového prostoru. Výstupem je vymezení sedmi hlavních typů přírodních krajin, jejichž geografická distribuce jasně odráží hlavní environmentální gradienty střední Evropy.

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