GEODIVERSITY ASSESSMENT AS AN INITIAL STEP IN IDENTIFYING AREAS OF GEOTOURISM POTENTIAL ON THE EXAMPLE OF ŠTIAVNICKÉ VRCHY, SLOVAKIA

Pavlo Zhyrnov[1], Ladislav Tolmáči[2], Anna Tolmáči[3]

1 Comenius University in Bratislava, Faculty of Natural Sciences, Department of Regional Geography and Regional Development, e-mail: zhyrnov1@uniba.sk, https://orcid.org/0000-0002-3972-3156

2 Comenius University in Bratislava, Faculty of Natural Sciences, Department of Regional Geography and Regional Development, e-mail: ladislav.tolmaci@uniba.sk, https://orcid.org/0000-0002-3391-3362

3 Comenius University in Bratislava, Faculty of Natural Sciences, Department of Regional Geography and Regional Development, e-mail: anna.tolmaci@uniba.sk, https://orcid.org/0009-0000-5786-0827

Abstract: Geodiversity encompasses the inherent variety found within the Earth's geological attributes, its terrain, and its soil composition. This includes the interconnectedness of these features, their specific qualities, and their influence upon both the natural world and human-made aspects of our surroundings. It is studied and assessed through various approaches, ranging from purely numerical methods to descriptive analyses, and combinations thereof. The notion of a geodiversity map, as introduced in this particular writing, aligns with this final methodological category – employing a blend of quantitative and qualitative techniques. Applying this approach to ascertain the geodiversity within a mountainous expanse (specifically, the Štiavnické vrchy), yields a comprehensive understanding of the region's natural diversity. Furthermore, it enables the identification of areas suitable for more intensive scrutiny or comparison. Such a geodiversity map serves as an ideal foundation for representing geotourism possibilities, visualized through the number and spatial distribution of geologically significant sites.

Keywords: geodiversity, assessment, geosites, geotourism, Štiavnické vrchy, Slovakia

1 INTRODUCTION

The term "geodiversity" gained traction in scientific circles during the 1990s and swiftly resonated with researchers globally (Serrano and Ruiz-Flaño, 2007; Gray, 2008; Brilha et al., 2018; Zwoliński et al., 2018; Vernham et al., 2023). It is understood differently depending on the context. It may refer to the natural variance of geologic components (rocks, minerals, and fossils), the topography (landforms and processes), and the soil, encompassing their interrelationships, characteristics, and effects on the surrounding natural and cultural aspects (Panizza and Piacente, 2009; Hjort et al., 2015). Alternatively, it can signify the natural variety on Earth's surface, inclusive of geological and geomorphological aspects shaped by both internal and external processes as well as human actions (Thomas, 2012). From an anthropocentric perspective, geodiversity denotes the diversity within the non-living aspects of nature in terms of its value to humans ecologically, economically, socially, and aesthetically (Anougmar et al., 2024). Furthermore, it's used as a component of sustainable development for use holistically to encapsulate the entire array of nature's non-living elements, which form the foundation for biodiversity (Crisp et al., 2023). Together, biodiversity and geodiversity comprise what is termed ecodiversity (Petrişor and Sârbu, 2010).

Geodiversity is generally regarded as the variability amongst elements of the relief, the lithosphere, the hydrosphere, the pedosphere, and the atmosphere and embodies the interconnectedness between landscapes and humans, including their cultural artifacts (Piacente, 2005). Gray (2019) formulated a definition that provides a highly comprehensive understanding of geodiversity and its importance in geoconservation.

Within the academic literature, geodiversity is connected to geoheritage as a neutral term to explain the diversity of inanimate nature on the planet, while geoheritage is a value-laden term employed to define the parts of geodiversity selected for the goal of geoconservation (Bétard and Peulvast, 2019).

Any human endeavor with direct ties to natural heritage should adhere to geoethics, which encompasses the investigation of the principles underlying appropriate human behaviors and practices about the Earth system (de Tarso Castro et al., 2021). Consequently, the concepts of geoheritage and geodiversity must be based on these principles when linked with geotourism. Increasingly, geodiversity serves as the foundation for the evaluation of non-living natural features that serve as geohabitats, which are then used for creating innovative tourist (geotourist) offerings. Often in literature, it constitutes a key part of evaluating geosites (Brilha, 2016).

As per the authors of this paper, evaluating the geodiversity of a given area might be the starting point for a deeper study of particular parts of mountain ranges and their evaluation for geotouristic purposes. Many quantitative and qualitative evaluation methods for geodiversity have been developed (Zwoliński et al., 2018), presenting numerous opportunities for refining, enhancing, or adjusting them to specific objectives.

Therefore, this article aims to assess geodiversity in the Štiavnické vrchy using the GIS-based method proposed by Zwoliński (2009) and to compare the resulting synthetic geodiversity map with the spatial distribution and tourist attractiveness of geosites as an initial step in identifying areas with high geotourism potential.

The authors formulated the following research questions: 1) Will the analysis of the geodiversity of Štiavnické vrchy reliably reflect its geodiversity and identify areas with the greatest geotourism potential for geosites that were explored during field reconnaissance based on tourist and geological guidebooks? 2) What can be offered for areas that lack geosites but at the same time have a high level of geodiversity, and how can the tourism potential of such areas be improved? The authors share the view, as with other scientists (Zwoliński et al., 2018), that geodiversity analysis using GIS can greatly contribute to predicting a holistic and integrated approach for ecosystem and geosystem services that promotes sustainable management of natural systems, generating geotourism products (Newsome and Ladd, 2022) or for the conscious management of protected areas and geoheritage (Crofts et al., 2015; Kaur, 2022).

2 LITERATURE REVIEW

2.1 Geodiversity

Geodiversity has recently seen a surge in attention, evident not just in scientific definitions of the term (Serrano and Ruiz-Flaño, 2007; Brilha et al., 2018; Gray, 2008; Zwoliński et al., 2018; Vernham et al., 2023) but, more importantly, in studies that use it to describe, evaluate, analyze, and assess particular regions (Benito-Calvo et al., 2009; Carrión-Mero et al., 2022; Albert and Kraja, 2025).

According to Zwoliński et al. (2018) methods used for describing, analyzing, and assessing geodiversity can be classified based on data source (direct and indirect, following Pellitero et al., 2015) or the method of approach (qualitative, quantitative, and qualitative–quantitative).

Qualitative methods are fundamentally based on the knowledge and experience of a researcher, typically an expert, or a group of experts (Zwoliński et al., 2018). Qualitative approaches utilize graphical representations, maps, and diagrams etc. (Ferrando et al., 2021; Najwer et al., 2022). Expert evaluations are supported by extensive literature reviews or by considerations of material goods and the benefits resulting from commercial activities within the described area. These methods are limited by their reduced objectivity (Zwoliński et al., 2018) and the challenges of application in different geographical areas.

Quantitative techniques rely on basic algorithms, measurements, calculations, and GIS analyses, potentially followed by additional calculations and statistical analyses (Forte et al., 2018).

The assessment of geodiversity is achieved via the analysis of indices (Micić Ponjiger et al., 2021) or map algebra (Pardo-Igúzquiza and Dowd, 2021), often incorporating a scoring method (Zwoliński et al., 2018).

Qualitative-quantitative methodologies represent, according to Zwoliński et al. (2018), the optimal approach for geodiversity assessment. This enables a more comprehensive – but still accessible – evaluation of geodiversity, incorporating elements from the analysis and preliminary assessment of its components, such as evaluating rock types and their ages through expert opinion (Benito-Calvo et al., 2009; Forte et al., 2018; Wolniewicz, 2021) or expert evaluations of aesthetic, scientific, and educational value, etc. (Zwoliński, 2009, 2018; Najwer et al., 2022). The combined methods typically culminate in a summary geodiversity map, often generated using digital summation techniques of map algebra (Benito-Calvo et al., 2009; Zwoliński, 2009, 2018; Najwer et al., 2022; Chrobak et al., 2021). The utilization of map algebra for data manipulation is becoming increasingly common in geodiversity assessment (Zwoliński, 2009, 2018; Chrobak et al., 2021; Micić Ponjiger et al., 2021; Najwer et al., 2022), establishing itself as a standard method worldwide. This research employs the same method.

2.2 Geoheritage and geotourism

While geodiversity provides the physical template of the abiotic environment, the concept of geoheritage emphasises those elements of geodiversity that possess particular scientific, educational, aesthetic, cultural or economic significance. Geoheritage is typically expressed through geosites – selected geological, geomorphological, hydrological and pedological features or landscapes that are recognised, interpreted and often protected for their value (Gray, 2019; Wolniewicz, 2021; Kaur, 2022). In this sense, geoheritage constitutes a bridge between geodiversity and geoconservation and underpins strategies for the sustainable use of abiotic nature (Dowling and Newsome, 2010; Newsome and Dowling, 2010; Farsani et al., 2011; Hose, 2012; Ólafsdóttir and Dowling, 2014; Hose, 2016; Dowling and Newsome, 2018; Ólafsdóttir and Tverijonaite, 2018).

Geotourism represents one of the main forms of such use. Most definitions understand geotourism as tourism that focuses on geology, geomorphology and landscape, promotes their understanding through interpretation and education, and simultaneously supports geoconservation and local development (Newsome and Ladd, 2022; de Tarso Castro et al., 2023). In practice, geotourism products are concentrated in and around geosites and geoparks, where the abiotic environment is combined with cultural and ecological values and embedded in attractive narratives.

Consequently, numerous authors have proposed methods for qualitative and quantitative evaluation of geosites and geomorphosites with respect to their scientific, educational, aesthetic and tourist importance (Piacente, 2005; Pralong, 2005; Pereira et al., 2007; Kubalíková, 2013; de Tarso Castro et al., 2023). These approaches typically distinguish between intrinsic (scientific, educational) and use-related (tourist, economic, accessibility, safety) criteria and lead to a synthetic score of the overall value or attractiveness of a site. Recent studies stress the need to embed such evaluations into a broader spatial context defined by geodiversity patterns and landscape structure (Hjort et al., 2015; Ferrando et al., 2021; Vernham et al., 2023).

In Central Europe and particularly in Slovakia, the assessment of geodiversity, geoheritage and geotourism has developed rapidly in the last two decades. Štrba et al. (2015) applied complex criteria to evaluate the geotourism potential of Slovak show caves, illustrating the importance of combining scientific value, accessibility and visitor experience. Konečný and Pachinger (2023) provided a detailed inventory and classification of geotopes in the Banská Štiavnica region, demonstrating the diversity of geosites and their potential for geotourism development at the local and regional scale.

Building on this literature, the present study adopts a geodiversity-first perspective. The geodiversity of the Štiavnické vrchy is quantified using a GIS-based index, and the resulting synthetic map is compared with the spatial distribution and tourist assessment of geosites. In this framework, geodiversity is treated as a neutral physical background, whereas geosites and their attractiveness represent the most visible manifestation of geoheritage and geotourism potential in the study area.

3 STUDY AREA

The Štiavnické vrchy (Štiavnica Mountains) form a Neogene volcanic range in central–southern Slovakia belonging to the Inner Western Carpathians and the geomorphological system of the Slovenské stredohorie (Slovak Central Volcanic Range) (Mazúr et al., 1986). The mountains are situated between the Hron and Ipeľ rivers and are surrounded by adjacent basins and highlands that frame the volcanic edifice. The central part of the range is occupied by the historic mining town of Banská Štiavnica and its surroundings, which represent one of the most important mining landscapes in Slovakia and strongly influence the cultural and touristic profile of the area (Kollár and Lacika, 2004).

According to the national geomorphological classification (Mazúr et al., 1986), the Štiavnické vrchy constitute a distinct geomorphological unit subdivided into four subunits (podcelky). The Sitnianska vrchovina subunit comprises the parts Sitno, Sitnianske predhorie, Štiavnická brázda and Prenčovská kotlina. The Hodrušská vrchovina subunit includes Vyhnianska brázda, Breznické podolie and Slovenská brána. Skalka and Kozmálovské vŕšky represent separate subunits of the mountain range. This hierarchical structure provides a consistent framework for the interpretation of geodiversity patterns and for the statistical summarisation of the results presented in this paper.

From a geological perspective, the Štiavnické vrchy represent the remnants of a large composite stratovolcano composed predominantly of andesitic lavas, pyroclastic deposits and volcaniclastic sediments of Neogene age (Konečný and Pachinger, 2023). Intensive hydrothermal activity, caldera collapse and subsequent erosion have produced a wide variety of volcanic landforms and rock types, including lava domes, intrusive bodies, collapse structures and extensive zones of hydrothermally altered rocks. The long-lasting exploitation of polymetallic ore deposits has left a dense network of underground workings and surface mining relics that significantly contribute to the geoheritage of the region (Mazúr et al., 1986) (Figure 1).

The highest part of the Štiavnické vrchy is Sitnianska vrchovina with the highest peak Sitno (1009 m), which protrudes impressively above the outskirts of the mountain range and from which magnificent distances are visible. Among the most attractive peaks of the Štiavnické vrchy, it is necessary to note Kalvária (726 m), Paradajs (939 m), Malý Tanád (860 m), Tanád (939 m), Glanzenberg (793 m), Zlatý vrch (850 m), and Banský vrch (865 m).

Figure 1 Location of Štiavnické vrchy on the territory of Slovakia (A) and their geomorphological zoning (B). Source: elaborated by authors

The most interesting geological objects are presented by lava flow with columnar jointing, bottom stratovolcanic structure Štangarígeľ, dyke of quartz-diorite porphyry Jergištôlňa, rock cliffs of amphibole-pyroxene andesite-biotite, upper structure of the Štiavnica Stratovolcano, andesite flow of the bottom stratovolcanic structure Suchá Voznica, travertine mounds Sklené Teplice, travertine mound Vyhne, basalt scoria cone the Pútikov Vŕšok Volcano, Kamenné more in Vyhne.

However, Štiavnické vrchy is rich not only in geological and geomorphological monuments. Here are the cleanest, freshest lakes called tajchy. Tajchy are artificial water reservoirs in the Štiavnické vrchy. Most of them were built to provide energy for the silver mines of Banská Štiavnica in the 18th century. At their height, tajchy comprised a sophisticated system of 60 reservoirs, connected by more than 100 km of channels and tunnels. 24 artificial lakes still exist and serve recreational purposes. Because of their historical value, tajchy was proclaimed by UNESCO to be a World Heritage Site on 11 December 1993, together with the city of Banská Štiavnica and technical historical monuments in its surroundings. Among the most touristically attractive and large tajches we can highlight jazero Počúvadlo, Veľká Richňavská nádrž, Kolpašsky tajch in Banský Studenec, Hodrušky dolny tajch in Hodruša-Hamre, Veľký Vindšachtský tajch in Štiavnické Bane, Rozgrund tajch in Banská Štiavnica, Bakomi tajch in Štiavnické Bane, Beliansky tajch in Banská Belá. Hot springs and the unique Parenica cave are located in the resort village of Sklené Teplice, which is used for medicinal and recreational purposes (Kelemen, 1986).

Among the attractive archaeological and architectural sites of Štiavnické vrchy it is worth highlighting námestie Svätej trojice, Starý and Nový zámok, Kalvária in Banská Štiavnica, hrad Glanzenberg, Žakýlsky hrad, Breznica hrad, kostol svätej Kataríny, hrad Marcus, hrad Sitno, kaštieľ Svätý Anton, Šášovský hrad.

As you can see, Štiavnické vrchy has significant tourist diversity. Every tourist can find something that will be interesting or useful for them. However, tourism resources in Štiavnické vrchy are unevenly distributed, and there are sites on their territory that today have low tourist attractiveness or even their complete absence. However, the absence of geosites in certain areas does not necessarily mean that there is no geodiversity. In this study, we will examine whether there is a correlation between the presence of geosites and the extent of geodiversity in these areas.

4 METHODOLOGY

4.1 Geodiversity assessment

The methodological framework for constructing a synthetic geodiversity map of the Štiavnické vrchy was initially inspired by Zwoliński's (2009) work, which the author then adapted. The key changes involved: 1) employing squares as the fundamental analytical units; 2) integrating geomorphons as components of relief types; 3) defining four to five classes within each of the six component maps, aligning with optimal utilization of the geodiversity map for geotourism.

A digital elevation model (DEM) acquired from the Bratislava Geodetic and Cartographic Institute's website, boasting a spatial resolution of 10 meters and utilizing the S-JTSK_Krovak_East_North coordinate system, served as the foundation for producing both a map of intricate morphometric indicators and a geomorphons map.

The creation of the geological map, land cover map, and soil quality map relied on the online atlas of landscapes of the Slovak Republic, accessible through the environmental portal of the Ministry of the Environment of the Slovak Republic. The Štiavnické vrchy area was then divided into a grid of 100-meter squares (a vector grid was generated using a command in ArcGIS ArcMap 10.0), and the respective values from the individual maps were subsequently allocated to each polygon or its raster equivalent (raster maps with a 10-meter resolution).

To derive the most objective representation of terrain forms from the digital terrain model, geomorphons (Stepinski and Jasiewicz, 2011; Jasiewicz and Stepinski, 2013) were employed. This tool facilitated the automatic and continuous segmentation of the entire area into regions that are virtually homogeneous in terms of their geomorphological relief form. This homogeneity is a crucial precondition for both quantification and assessment, particularly regarding geodiversity. Conversely, this process produces a somewhat simplified portrayal. A potential limitation is that, in reality, diverse landforms exhibit varying dimensions and significant relief elements for geodiversity considerations, while perhaps numerous, may cover smaller spatial extents. This is relevant to the summit category, where the tool identifies only the immediate vicinity of the peak's inflection point as a summit, with the broader area being classified as a slope category (Jasiewicz and Stepinski, 2013).

For deriving the most unbiased terrain representations from the digital terrain model, we employed geomorphons (Stepinski and Jasiewicz, 2011; Jasiewicz and Stepinski, 2013). This method facilitated the automatic, continuous segmentation of the entire study region into zones that exhibited near-uniformity in their geomorphological characteristics. Such a division serves as a fundamental requirement for both quantification and assessment, encompassing aspects relevant to geodiversity. However, a certain degree of simplification is inherent in this approach.

The drawback here lies in the fact that natural landscapes display a range of dimensions for different forms. Also, geodiversity-relevant features, although potentially numerous, can exist within limited spatial extents. A pertinent example involves summit features: the algorithm identifies only the direct vicinity of the peak's inflection point as a summit, relegating surrounding broader areas to the slope classification (Jasiewicz and Stepinski, 2013).

The suite of analytical maps generated comprised a complex morphometric geodiversity index map, alongside a geological geodiversity map, a soil cover quality diversity map, a relief geodiversity (geomorphons) map, and a land cover geodiversity map. The surface analysis hinges on five principal parameters. While other factors, such as the existence of caves, lakes, and streams, are noted in relevant literature as influencing the geodiversity index, they're typically viewed as integral landscape features, thereby aligning with the main components previously listed. The generation of a composite geodiversity map involved averaging the five uniformly distributed analytical indices from each map, yielding an arithmetic mean for the final geodiversity index. This final index was then evenly distributed across five equally weighted categories, graded to span from “very low geodiversity” to “very high geodiversity” (Figure 2).

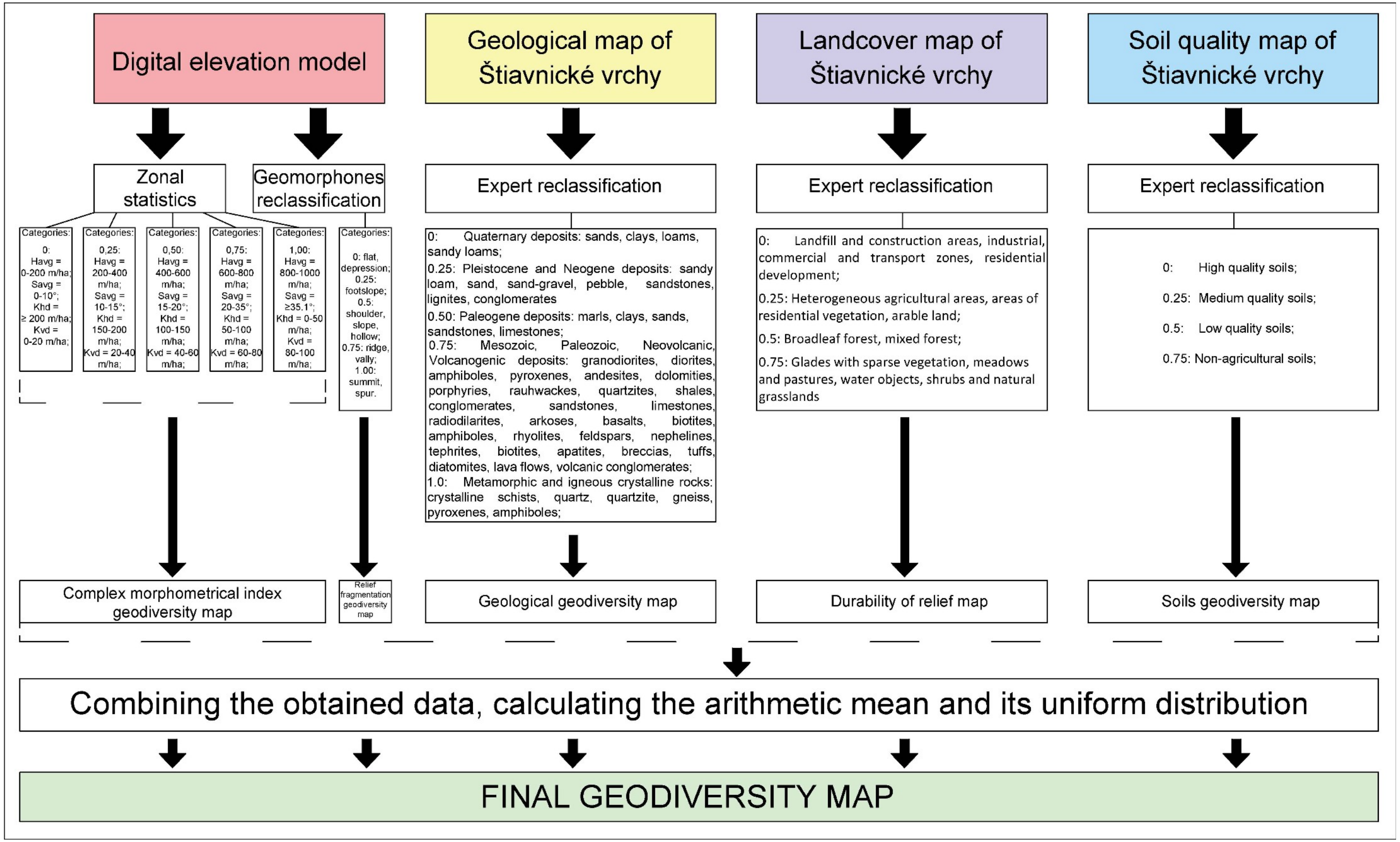

Figure 2 Methodology for creating a synthetic map of geodiversity. Source: elaborated by authors

The formula employed for calculating the final geodiversity index can be expressed as:

Gi = (Mi + GMi + GEOi + Li + Si) / 5

Here, Gi signifies the geodiversity index, Mi the complex morphometric index, GMi the geomorphons index, GEOi the geological index, Li the land cover index, and Si the soil quality index. A critical point is the even distribution of the composite geodiversity index across the five previously described classifications.

The Štiavnické vrchy geodiversity map was combined with point objects of geosites in the final stage. The Štiavnické vrchy geosite database was created based on information from the guidebook "Štiavnické vrchy – Slovenské stredohorie" by Daniel Kollár (Kollár and Lacika, 2004) and the book "Geotopes of the Banská Štiavnica Geopark", prepared by the staff of the Dionýz Štúr State Geological Institute (Konečný and Pachinger, 2023). Each geosite was explored during field trips, and the exact location of each geosite was recorded using the "Mapy.cz" software installed on a mobile phone. The GPX files were transformed into point shapefiles and transferred to a map of the study area in ArcGIS ArcMap 10.0 software. Furthermore, during field studies, each geosite was evaluated according to six evaluation categories: scientific, aesthetic, cultural-historical, ecological, socio-economic, and a safety category (Likhacheva and Timofeev, 2002; Pralong, 2005; Pereira et al., 2007; Andreychuk, 2007; Trofimova, 2012; Kubalíková, 2013; Štrba et al., 2015; Zhyrnov, 2015).

Each category consists of a certain number of evaluation criteria, which, depending on the degree of expression, were assessed with points from 0 to 1, where 0 reflects the complete absence of a certain characteristic, and 1 reflects the most pronounced characteristic of the criterion. The final score for each criterion of a particular category was calculated as the arithmetic mean of the sum of all criteria divided by the number of criteria. It should be noted that the final map of tourist assessment of geosites was supplemented with a diagram of the attractiveness values of each geosite, which was created in the Microsoft Excel program. The final tourist assessment of the geosites of the Štiavnické vrchy area was divided into three categories: for sites with a low attractiveness value, a threshold with values up to 0.50 was recognized, sites of average attractiveness occupied a niche from 0.51 to 0.60, and highly attractive sites were recognized as those that received a rating of 0.61 and higher (Figure 3).

At the end, a conclusion was made about the spatial distribution of geosites of different levels of attractiveness in areas with different indices of geodiversity.

4.2 Geosite inventory and tourist assessment

The spatial distribution and tourist attractiveness of geosites in the Štiavnické vrchy were assessed using a combination of existing geosite inventories and field verification. The starting point was a previously compiled database of geotopes and geosites in the wider Banská Štiavnica region, which includes a broad spectrum of geological, geomorphological, hydrological and mining-related features (e.g. underground workings, open pits, spoil heaps, lava domes, rock outcrops, waterfalls and

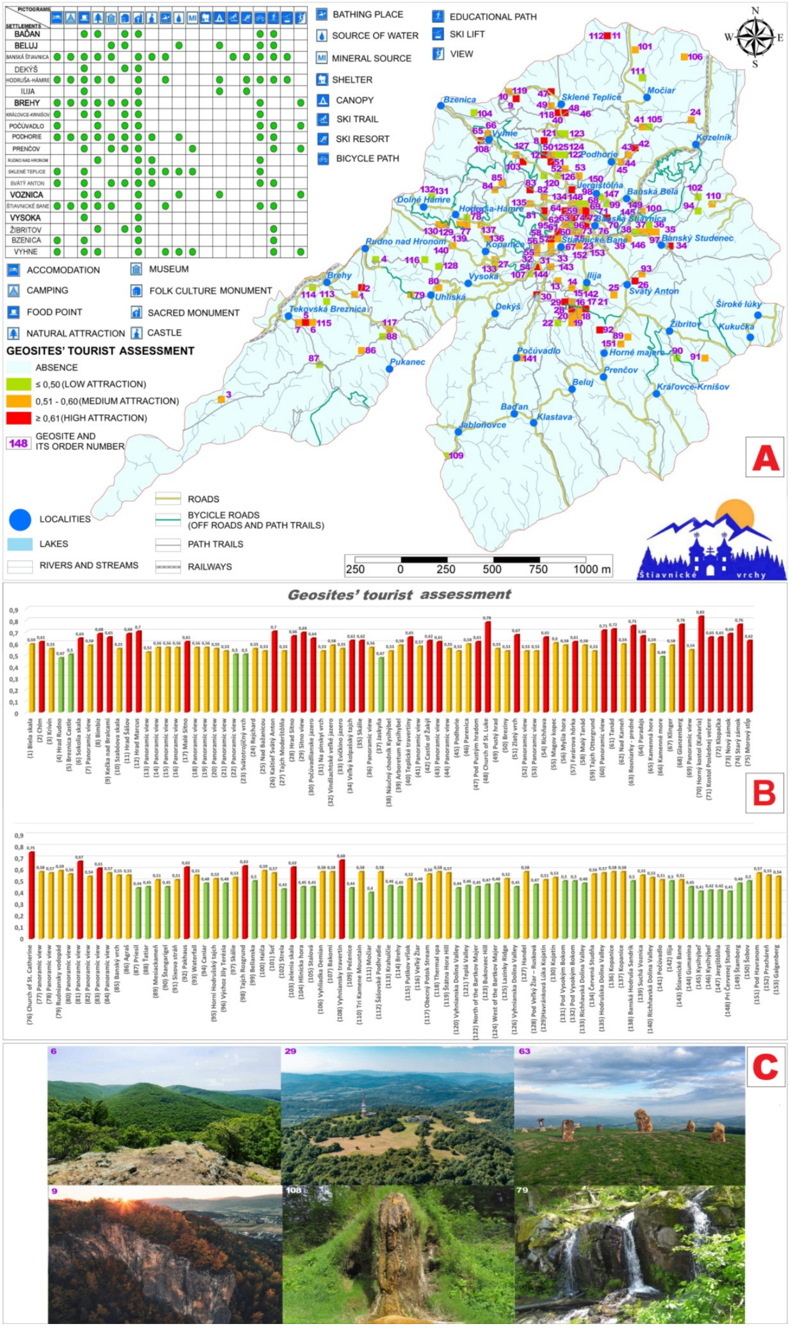

Figure 3 Map of tourist assessment of geosites on the territory of Štiavnické vrchy, (A) diagram of geosites' tourist assessment, (B) and photos of geosites according to their location (C) on the map (C). Source: elaborated by authors

anthropogenic landforms associated with water management). The inventory was reviewed and updated using recent publications and cartographic sources, and all sites were checked in the field and georeferenced using GPS.

For each geosite, a set of criteria describing its value and attractiveness was evaluated based on approaches proposed by earlier authors (Piacente, 2005; Pralong, 2005; Kubalíková, 2013; Štrba et al., 2015; Zhyrnov, 2015; Brilha, 2016). The criteria were grouped into six main categories: (i) scientific value, (ii) aesthetic value, (iii) cultural-historical value, (iv) ecological and environmental value, (v) socio-economic and functional value, and (vi) safety and accessibility. Each criterion was scored on a semi-quantitative scale from 0 to 1, where 0 indicates the absence of the given attribute and 1 represents its maximum expression in the regional context.

The partial scores for individual criteria were normalised and aggregated within each category to obtain category-specific indices. Subsequently, a synthetic tourist attractiveness index for each geosite was calculated as the arithmetic mean of the six category indices. Following Štrba et al. (2015) and similar studies, threshold values were used to distinguish three levels of attractiveness: low (0.00 – 0.40), medium (0.41 – 0.60) and high (≥ 0.61). In the context of this study, geosites with an overall score of 0.61 or higher are interpreted as highly attractive and particularly relevant for geotourism development. The resulting point layer of geosites with assigned tourist attractiveness indices formed the main input for the comparison with the geodiversity map.

4.3 Integration of geodiversity and geosites

To explore the relationship between geodiversity patterns and geotourism potential, the synthetic geodiversity map and the geosite database were integrated within a GIS environment. The geodiversity index raster with a cell size of 10 m was used as a continuous representation of abiotic diversity across the entire Štiavnické vrchy. Each geosite was represented by a point located at the centre of the site or, in the case of more extensive objects, by a representative point capturing the most characteristic part of the geosite.

First, the geodiversity index value of the raster cell containing each geosite point was extracted. This allowed the direct comparison of the geodiversity level and the tourist attractiveness index at the location of each geosite. In addition, circular neighbourhoods with a radius of several raster cells were used to calculate local statistics (minimum, maximum and mean geodiversity index) around each site, which enabled us to characterise the geodiversity of the immediate surroundings of geosites. The extracted values were subsequently analysed to identify whether highly attractive geosites tend to cluster in areas of medium to very high geodiversity or whether geosites also occur in areas of lower geodiversity.

Second, the distribution of geodiversity classes and geosites was summarised for the geomorphological subunits of the Štiavnické vrchy as defined by Mazúr et al. (1986). The study area was subdivided into the Sitnianska vrchovina, Hodrušská vrchovina, Skalka and Kozmálovské vŕšky subunits, and, where appropriate, into their constituent parts (Sitno, Sitnianske predhorie, Štiavnická brázda, Prenčovská kotlina, Vyhnianska brázda, Breznické podolie and Slovenská brána). For each subunit, the areal proportion of geodiversity index classes and the number and share of geosites with low, medium and high attractiveness were calculated. This hierarchical framework provides a coherent basis for the interpretation of the results presented in Section 5 and for the discussion of spatial patterns of geodiversity and geotourism potential in Section 6.

5 RESULTS

The resultant synthetic geodiversity map is constituted by the integration of the five component maps, which will undergo subsequent analysis.

5.1 Complex morphometrical index geodiversity map

The complex morphometric index included the calculation of the average height value, average slope steepness value, horizontal dissection index, and vertical dissection index. All these indices were calculated for each cell with an area of 1 ha. The above indices were calculated largely using the Zonal Statistics tool of the Spatial Analyst analytical panel in the ESRI ArcGIS ArcMap 10.0 software product. All these groups of indices were evenly distributed and classified into five classes from 0 to 1. The higher the value, the higher the values are characteristic of each cell, and the higher the implied geodiversity in the calculation cell. The largest number of cells (29.4%) corresponded to the average value of "0.5" of the complex morphometric index, followed by the categories of 0.25 (24.3% cells) and 0.75 (21.5%). The cell values for the lowest 0 index (15.9%) and the highest 1 index (8.9%) are relatively small (Figure 4).

The highest values are typical for the geomorphological regions of Hodrušská hornatina and Sitno, followed by Skalka and Sitnianske predhorie. Lower values are typical for Štiavnická brázda and Vyhnianska brázda, and the ranking is rounded out by Prenčovská kotlina, Kozmálovské vŕšky, Breznické podolie, and Slovenská brána.

To sum up, analyzing the geodiversity of Štiavnické vrchy based on the map of the complex morphometric indicator of the relief, we can clearly state that in most of the territory, we are dealing with an average and slightly lower and slightly higher degree of variability of the morphometric index (classes 0.5, 0.25 and 0.75). The distribution of the highest index of geodiversity (class 1.0) is associated with the most elevated and dissected mountainous areas, and, in general, the values of the complex morphometric index correlate with altitude.

5.2 Relief fragmentation geodiversity map

The basis for this partial analysis was the map of geomorphones, which was built based on the digital elevation model of Štiavnické vrchy in the SAGA GIS 9.6.1 application (Stepinski and Jasiewicz, 2011; Jasiewicz and Stepinski, 2013). The area was divided into 10 basic morphological categories, which were assigned five values of geodiversity (Figure 5).

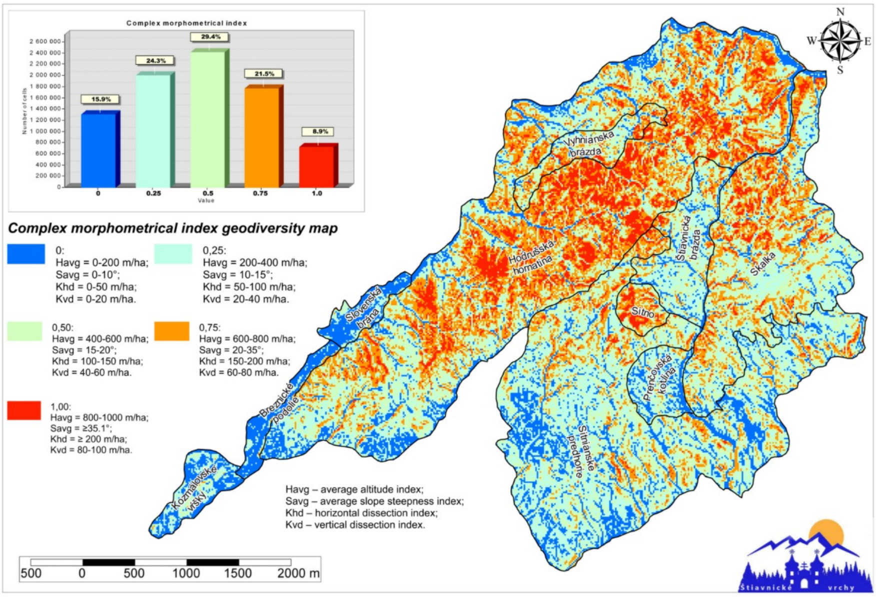

Figure 4 Complex morphometrical index geodiversity map of Štiavnické vrchy. Source: elaborated by authors

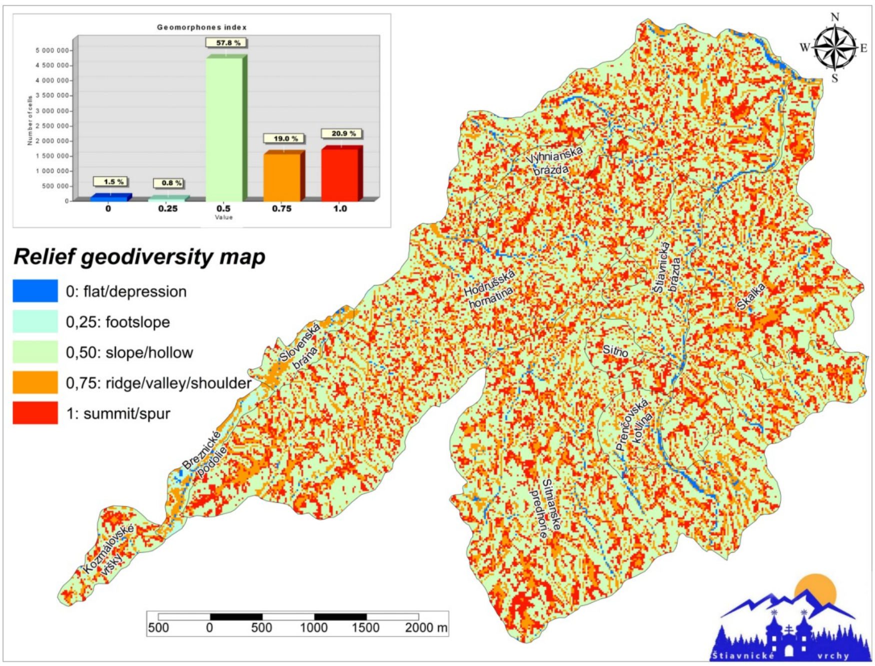

Figure 5 Relief fragmentation geodiversity map of Štiavnické vrchy. Source: elaborated by authors

The largest number of evaluation cells corresponded to the 0.5 “slope/hollow” category (57.8%), followed by the 1 “summit/spur” category (20.9%) and the 0.75 “ridge/valley/shoulder” category (19.0%). The smallest number of evaluation cells was found in the 0 “flat/depression” category (1.5%) and the 0.25 “footslope” category (0.8%). This trend can be observed for each geomorphological region of the Štiavnické vrchy territory.

Summing up, analyzing relief geodiversity in the Štiavnické vrchy based on a map of geomorphones, it can be clearly stated that in the majority of the area, there is a medium degree of relief variation (class 0.5). The occurrence of the higher geodiversity classes (1.0 and 0.75) is also relatively important. The lowest classes of geodiversity occur in low-lying basin sites.

5.3 Geological geodiversity map

The author proceeded from the consideration that the more mechanically resistant rock is to weathering processes, the longer the relief forms composed of such rocks will exist. Thus, the physical and mechanical properties of rocks are included in the assessment classification in the context of geodiversity. The dominant category of assessment cells for geological geodiversity in Štiavnické vrchy was the value of 0.75 (74.1% cells). The cover deposits here are mainly represented by Mesozoic, Paleozoic, Neovolcanic, and Volcanic deposits in the form of rock formations of various rocks (granodiorites, dolomites, porphyrites, conglomerates, biotites, etc.). All of the above rocks are resistant to abrasion and weathering, which means that landforms composed of such rocks will exist for a very long time. The strength of these rocks is only slightly inferior to that of metamorphic and igneous rocks, which are represented by crystalline schists, quartz, quartzite, gneiss, pyroxenes, and amphiboles. These rocks are characterized by the highest strength characteristics and therefore occupy the highest assessment level of geological diversity 1.0, although the number of such cells in the Štiavnické vrchy area is the smallest and amounts to only 0.5% of cells.

The second place, by a significant margin, belongs to the Quaternary deposits with a value of 0 (14.5% cells). Quaternary deposits are mainly concentrated in river and stream valleys, accumulation areas, and are often represented by landslide, deluvial-colluvial deposits. In general, the area of mountains covered by Quaternary deposits is relatively small.

The third and fourth places with classes of 0.25 and 0.5, respectively, according to the index of geological diversity were taken by Pleistocene, Neogene, Paleogene deposits, which are represented by sedimentary rocks such as loams, sands, sandstones, lignites, conglomerates and limestones (6.9% and 4.0% assessment cells, respectively). These rocks are confined to the zones of distribution of Quaternary deposits.

Summarising and analyzing the geological diversity in Štiavnické vrchy, it can be clearly stated that the majority of the territory is characterized by a high degree of geological diversity (class 0.75), however, a small part of the territory in the accumulation zones and river valleys is confined to Quaternary, Pleistocene, Neogene and Paleogene deposits (classes 0, 0.25 and 0.5). The highest class of geodiversity

(1.0) is found within the Hodrušská hornatina geomorphological region and is represented by rocks with crystalline structural lattices, but this class is the smallest in terms of area of distribution (Figure 6).

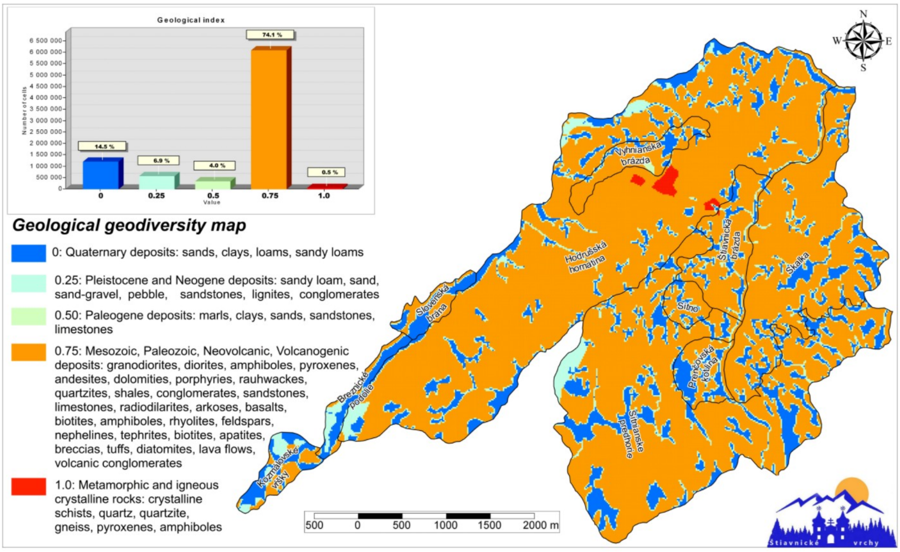

Figure 6 Geological geodiversity map of Štiavnické vrchy.
Source: elaborated by authors

5.4 Land cover geodiversity map

The land cover of Štiavnické vrchy is such that no elements correspond to the highest value of 1.0; there are only 4 categories from 0 to 0.75. The highest value of 0.75 was assigned to the land cover that maximally exposes rocks; these included glades with sparse vegetation, meadows and pastures, shrubs and natural grasslands, and water objects. The total number of evaluation cells for this indicator was 9.7% (Figure 7).

The largest number of assessment cells was assigned to the average class 0.5 (69.5%) – these are areas covered mainly by forests, which is not surprising since the average altitudes of Štiavnické vrchy correspond to lower and upper mountain forests. This category includes broadleaf forest and mixed forest. This land cover category is by far the most dominant in the study area.

The smallest categories were industrial, commercial, and transport zones, residential development, landfill, and construction areas, with a value of 0 (2.3% evaluation cells). The land cover features in the form of construction areas are most pronounced in the most heavily urbanized geomorphological region of Štiavnická brázda; there are no other features in the distribution of land cover by geomorphological regions of Štiavnické vrchy.

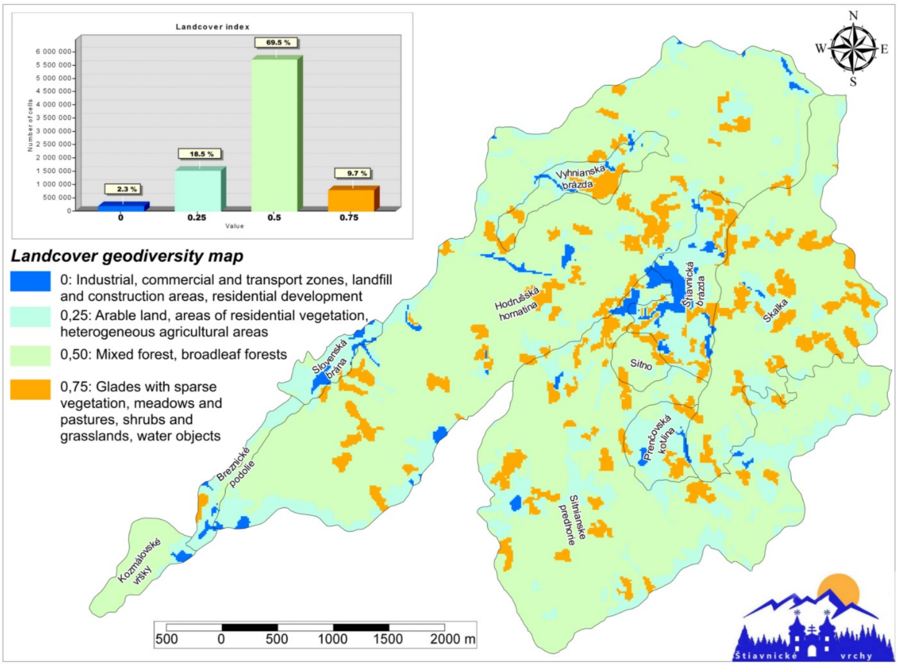

Figure 7 Landcover geodiversity map of Štiavnické vrchy.
Source: elaborated by authors

The second largest land cover type (classified as 0.25) is arable land areas of resident vegetation, heterogeneous agricultural areas, which lags far behind the dominant 0.5 class, with only 18.5% assessment cells.

In conclusion, analyzing the geodiversity of the land cover of Štiavnické vrchy based on the atlas of landscapes of the Slovak Republic, it can be clearly stated that in most of the territory, there is a low degree of differentiation of the land cover (class 0.5 is the most pronounced and dominant). The highest elevations contain areas with the highest geodiversity (class 0.75), but their area is small and they are geographically dispersed throughout the Štiavnické vrchy. The lowest class of geodiversity is observed within the larger cities, especially within the urban agglomeration of Banská Štiavnica.

5.5 Soils geodiversity map

The soil geodiversity map is based on the principle that the most diverse landscapes and natural vegetation can arise in areas with non-agricultural soils.

Analyzing the soil quality map of Štiavnické vrchy, it can be concluded that the most common class of soils is non-agricultural soils, which corresponds to the highest value of 0.75 (67.1% cells, respectively). This fact is because the territory under study is mountainous, for which agricultural activity is not typical and for which agricultural soils are not characteristic. This is also the main reason due to the small distribution of low-, medium-, and high-quality soils.

The second most common type of soil is low-quality soil, which corresponds to class 0.5 (20.1% cells). They are followed by medium-quality soil (class 0.25, 10.2% cells) and high-quality soil (class 0, 2.6% cells), which are even less common.

When speaking about spatial distribution, it is worth noting that such geomorphological regions as Štiavnická brázda, Prenčovská kotlina, Kozmálovské vŕšky, Vyhnianska brázda, Breznické podolie, and Slovenská brána have in their structure a greater number of low-, medium-, and high-quality soils, which, as a result, provide lower geodiversity. Medium- and high-quality agricultural soils are located in the Hron River valley on the southwestern outskirts and the flattest areas of Štiavnické vrchy. The geomorphological region of Štiavnická brázda has a high rate of low-quality soils (Figure 8).

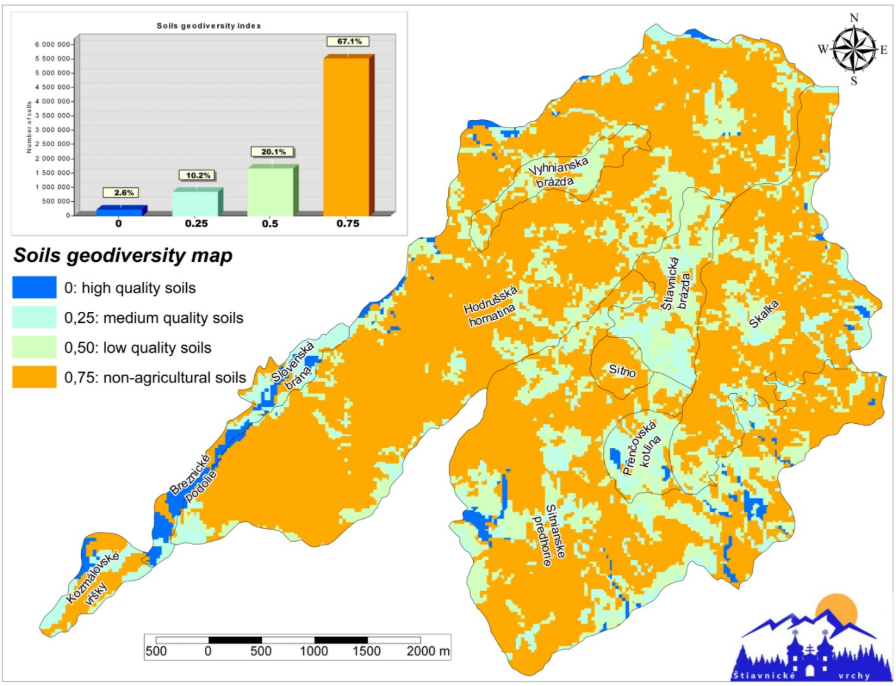

Figure 8 Soil geodiversity map of Štiavnické vrchy. Source: elaborated by authors

5.6 Synthetic geodiversity map and location of geosites with different levels of attraction

The synthetic geodiversity map was created from a combination of the five component maps described above, for which all component values were equally weighted and distributed evenly within each indicator. By summing the individual elements with equal weights and dividing them by the number of assessment categories, the final geodiversity index was determined, and a synthetic geodiversity map was created. The values themselves from zero to one, where zero represents areas with the lowest geodiversity and one represents areas with the highest geodiversity, were evenly distributed, and the following geodiversity indices were obtained: 0 (very low geodiversity): 0 – 0.10; 0.25 (low geodiversity): 0.11 – 0.20; 0.5 (medium geodiversity): 0.21 – 0.30; 0.75 (high geodiversity): 0.31 – 0.40; and 1 (very high geodiversity): 0.41 – 0.50 (Figure 9).

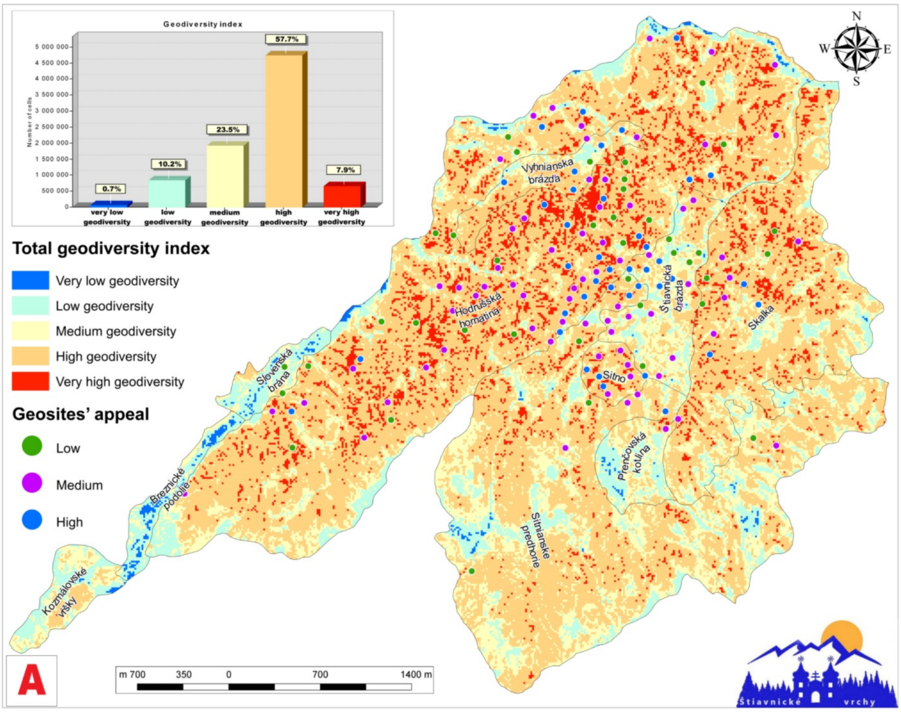

Figure 9 Synthetic geodiversity map and location of geosites with different levels of attraction. Source: elaborated by authors

Analyzing the geodiversity map, we can conclude that Štiavnické vrchy as a whole belongs to a geomorphological region with a high and medium level of geodiversity. However, still high values are dominant in the region (57.7% estimated cells of class 0.75). Grade 0.5 ranks second, corresponding to sites with a medium level of geodiversity (23.5% cells). A significant downward gap is class 0.25, which corresponds to sites with low geodiversity (10.2% cells). This is followed by the highest geodiversity value of 1, corresponding to 7.9% estimated cells. The final class is 0, corresponding to sites with very low geodiversity (0.7%). The total percentage of high and very high geodiversity in Štiavnické vrchy was around 65%, while areas with low and very low geodiversity scored only 11%.

The geomorphological areas with the highest geodiversity index are Sitno and Hodrušská hornatina, followed by the geomorphological area Skalka. The geomorphological areas Sitnianske predhorie, Štiavnická brázda, and Vyhnianska brázda have more average values. Geomorphological areas with relatively low geodiversity are represented by Prenčovská kotlina, Kozmálovské vŕšky, Breznické podolie, and Slovenská brána.

The above analysis is undoubtedly most heavily influenced by a diversity of relief, values of the complex morphometric index (especially values of relative heights), and geological structure. The results of these analyses confirm the assumption of the author that values of geodiversity will be highest in areas with the highest elevations and lowest in river valleys and interridge basins.

One indicator of the geotourism potential of the study area is the number of geosites found and described in the area. In general, the presence of geosites coincides with areas of medium, high, and very high geodiversity, especially in the geomorphological areas of Sitno, Hodrušská hornatina, and Skalka. An interesting feature is that, for example, in the Štiavnická brázda area, which is so rich in various geosites, the geosites themselves are often confined to areas of low geodiversity. This is primarily because here a large number of geosites are located in the main city of Štiavnické vrchy Banská Štiavnica and are represented by man-made geoheritage and tourism sites. It should also be noted that there is no clear relationship between areas of high geodiversity and high attractiveness of geosites, as medium and high attractiveness geosites can be both confined to such areas and located in areas of low geodiversity, as can be seen in the geomorphological areas of Štiavnická brázda, Vyhnianska brázda, and Slovenská brána.

A synthetic geodiversity map allows a comprehensive assessment of the geodiversity of the study area. This map can also serve as a starting point for designating areas of exceptional natural value and then for selecting specific sites that could represent a tourist attraction or geosites. However, until now, geodiversity assessment (surface) and geosites assessment (point) have not been analyzed together. Geosites have been assessed using other assessment methods related to the assessment of a specific site rather than the whole area (Mucivuna et al., 2019). In general, in Štiavnické vrchy, areas of high or medium geodiversity coincide with the presence of geosites of varying degrees of attractiveness. However, in some places, the lack of correlation between these variables does not mean that in places with low geodiversity, there are no interesting places that could become geosites.

From the above analysis, the geotourism potential can be characterized as high (57.7% of the total area) and medium (23.5%), but if we take into account individual areas of Štiavnické vrchy, there are areas with very high geotourism potential and very high geodiversity, a large number of geosites (e.g., Hodrušská hornatina, Sitnianske predhorie, Sitno, Skalka). These areas are currently among the most popular tourist destinations and require special protection. Weathering processes do not have the best effect on the condition of some attractive landforms, and some attractive areas may have dangerous erosion and gravitational geomorphological processes. The underground waters that have created the picturesque artificial lakes called tajchy are under anthropogenic pressure; therefore, sustainable development of new geoattractive sites in these areas should be based on the principles of geoethics, as mankind may become much more dependent on these water resources in the future.

At the same time, the northern, eastern, southern, and south-western parts of Štiavnické vrchy are characterised mainly by high and medium geodiversity, but there are no geosites in these areas, or only a small number of them. Given this circumstance, it is necessary to consider administrative measures that could contribute to improving the tourist potential of these areas and attracting potential tourists.

6 DISCUSSION

At the beginning of this article, we asked some research questions about the geodiversity, tourism potential, and geosites of Štiavnické vrchy. We propose to analyze them and provide adequate answers in this chapter of the article.

6.1 Will the analysis of the geodiversity of Štiavnické vrchy reliably reflect its geodiversity and identify areas with the greatest geotourism potential for geosites that were explored during field reconnaissance based on tourist and geological guidebooks?

Taking into account the multi-component analysis of the data used to reflect the level of geodiversity of the Štiavnické vrchy area, we, in general, believe that the final result in the form of a geodiversity index map is convincing and adequately reflects the picture of the geodiversity of the mountain range. A controversial point, in our opinion, is the analysis of the geodiversity of the quality of the soil, since the analysis of the landcover geodiversity partially takes into account the information on the relationship between the type of soil and the land cover of the studied area. When assessing the geodiversity of the territories, some researchers also resort to the analysis of such parameters as the presence of caves, lakes, watercourses (Zwolinski and Stachowiak, 2012), which also affect the geodiversity index, but are in some way a component of the relief and, therefore, one of the main components analyzed in the Relief fragmentation geodiversity map. Also, some researchers (Ferrando et al., 2021; Chrobak et al., 2021) assign different analytical weights to certain parameters under study, thereby assigning more dominant factors for diversity assessment based on expert knowledge. However, we believe that the methodology described in the current article also quite clearly identified the most and least geodiverse areas of the studied mountain range, and the coefficient of possible error of the geodiversity index is insignificant and corresponds to the real picture of the geodiversity of Štiavnické vrchy. However, when comparing geodiversity areas with the location of geosites of different levels of attractiveness, certain comments arise. On the one hand, it is obvious that since the dominant value of the geodiversity index is "high" (57.7%), the distribution of geosites will mainly correspond to areas with the specified geodiversity index, regardless of the attractiveness of the geosite (66.7% of low-attractiveness geosites, 64% of medium-attractiveness geosites, and 69.2% of highly attractive geosites are located in areas with a high geodiversity index). On the other hand, we see that large areas in the north, east, south, and southwest of Štiavnické vrchy are represented by fairly geodiverse areas, but geosites in these areas are absent or present in insignificant quantities. This suggests that geosites will not always be located in areas with a high level of geodiversity, and the level of attractiveness of a geosite will not always correspond to high rates of geodiversity, since the geosite itself can be represented by a man-made object, especially within settlements, and natural diversity may in no way affect the tourist attractiveness of the attraction. However, the presentation of the general geodiversity for a particular mountainous region indicates those places which are worth studying and analyzing in more detail in connection with the possible creation of further tourism products in areas with a high level of geodiversity, since natural conditions are conducive to this.

6.2 What can be offered for areas that lack geosites but at the same time have a high level of geodiversity, and how can the tourism potential of such areas be improved?

Despite the high geodiversity of Štiavnické vrchy, the northern, eastern, western, and southwestern parts of the mountain range are characterized by the absence or small number of geosites, even though natural conditions are attractive for their creation. In our opinion, these geosites can be created artificially, which requires practical, administrative, and financial efforts; however, ultimately, all these efforts will be justified, as they will ensure sustainable environmental development and economic prosperity of the region by increasing the tourist attractiveness of such territories.

Given the primacy of forests as Štiavnické vrchy's principal natural resource, a suitable approach for the identified areas would be the establishment of forestry arboretums. These would emulate the example of Arborétum Kysihýbeľ, situated on the eastern periphery of Banská Štiavnica (Lesnícke arborétum Kysihýbeľ, 2022). These arboretums could cultivate uncommon forest species, introduce tree varieties suited to various climates, facilitate landscape design, and provide educational hiking trails, amongst other potential features. Another feasible avenue is the development of varied museums tailored to the particular historical, cultural, and natural characteristics of these areas (Kim et al., 2020). Gastronomic tourism also offers potential, involving the establishment of cafes and restaurants offering Slovak and international fare, inclusive of regional specialities (Cunha, 2018). Furthermore, the forested zones in Štiavnicé vrchy's southern region are interspersed with small valleys, which could be utilized for equestrian activities (Helgadóttir and Sigurðardóttir, 2008).

The expanded development of tourism in these locales hinges on the improvement of existing tourist trails, encompassing clearing, leveling, and general upkeep.

Currently, these trails are in a less-than-ideal condition. The proposed enhancements should encompass forest walks, recreational opportunities near water sources and within the forest, skiing and cycling tourism, sporting events (including cross-country competitions and triathlons), forest and sporting orienteering, the creation of ecpeulo-trails, and guided experiences showcasing the natural, historical, and cultural heritage of the forests (Font and Tribe, 2000). Additionally, the promotion of direct observation and familiarization with both fauna and flora within their natural environment is desirable. However, these initiatives present significant economic and labor demands, necessitating robust support from state bodies or through tourism development initiatives funded by various European Union programs.

7 CONCLUSION

The comprehensive exploration and discourse concerning geodiversity, alongside its suitability for geotourism, have led to these key findings:

– the geodiversity map showcased within the publication represents a further refinement of the map algebra methodology initially introduced by Zwoliński (2009);
– when compiling the Štiavnické vrchy geodiversity map, morphometric relief indicators, a geomorphon map, a geological map, a landcover map, and a soil quality map were taken into account;
– the analysis of the geodiversity of the Štiavnické vrchy mountain range is the first step in identifying areas requiring a more detailed analysis of geotourism potential;
– the geodiversity index is high (57.7%), indicating that most geosites are found in areas with this index. However, many geodiverse regions, particularly in Štiavnické vrchy, lack significant geosites. This shows that geosites and their attractiveness do not always align with high geodiversity, as man-made objects can also influence tourism appeal;
– the study on geodiversity in the Štiavnické vrchy area yielded a map indicating the region's diversity, but the quality of the soil analysis raised debate. The study identified high and low geodiversity areas with minimal errors, suggesting that attractiveness doesn't always align with geodiversity;
– despite Štiavnické vrchy's high geodiversity, the northern, eastern, western, and southwestern mountain ranges lack geosites. Artificial creation could enhance environmental development and economic prosperity by establishing forests, arboretums, museums, gastronomic tourism, and equestrian activities, requiring practical, administrative, and financial efforts;
– the expansion of tourism in these areas requires improving existing tourist trails, including clearing, leveling, and maintenance. Enhancements should include forest walks, recreational opportunities, skiing, cycling, sporting events, eco-trails, guided experiences, and promoting direct observation of fauna and flora. However, these initiatives require substantial economic and labor support.

References

ALBERT, G., KRAJA, D. 2025. Geodiversity and land cover diversity from coast to mountains in Northern Albania. *Moravian Geographical Reports*, 33(1), 56-67. DOI: https://doi.org/10.2478/mgr-2025-0005

ANDREYCHUK, V. N. 2007. *Karst as a geoecological factor*. Sosnowiec – Simferopol: Jacek Skalmerski's Computer Laboratory. [online] [cit. 2025-08-15]. Available at: <https://hinko.org/hinko/Dowloads/11/1/XI-1-35.pdf>

ANOUGMAR, S., MEESTERS, A., VAN REE, D., COMPERNOLLE, T. 2024. The dilemma of valuing geodiversity: geoconservation versus geotourism. *Philosophical Transactions of the Royal Society A*, 382(2269), 1-18. DOI: https://doi.org/10.1098/rsta.2023.0049

BENITO-CALVO, A., PÉREZ-GONZÁLEZ, A., MAGRI, O., MEZA, P. 2009. Assessing regional geodiversity: the Iberian Peninsula. *Earth surface processes and landforms*, 34(10), 1433-1445. DOI: https://doi.org/10.1002/esp.1840

BÉTARD, F., PEULVAST, J. P. 2019. Geodiversity hotspots: Concept, method and cartographic application for geoconservation purposes at a regional scale. *Environmental management*, 63(6), 822-834. DOI: https://doi.org/10.1007/s00267-019-01168-5

BRILHA, J. 2016. Inventory and quantitative assessment of geosites and geodiversity sites: a review. *Geoheritage*, 8(2), 119-134. DOI: https://doi.org/10.1007/s12371-014-0139-3

BRILHA, J., GRAY, M., PEREIRA, D. I., PEREIRA, P. 2018. Geodiversity: an integrative review as a contribution to the sustainable management of the whole of nature. *Environmental Science and Policy*, 86, 19-28. DOI: https://doi.org/10.1016/j.envsci.2018.05.001

CARRIÓN-MERO, P., DUENAS-TOVAR, J., JAYA-MONTALVO, M., BERREZUETA, E., JIMÉNEZ-ORELLANA, N. 2022. Geodiversity assessment at regional scale: Ecuador as a case study. *Environmental Science and Policy*, 136, 167-186. DOI: https://doi.org/10.1016/j.envsci.2022.06.009

CHROBAK, A., NOVOTNÝ, J., STRUŚ, P. 2021. Geodiversity Assessment as a First Step in Designating Areas of Geotourism Potential. Case Study: Western Carpathians. *Frontiers in Earth Science*, 9, 1-20. DOI: https://doi.org/10.3389/feart.2021.752669

CRISP, J. R., ELLISON, J. C., FISCHER, A., TAN, J. S. 2023. Geodiversity inclusiveness in biodiversity assessment. Progress in Physical Geography: *Earth and Environment*, 47(3), 414-437. DOI: https://doi.org/10.1177/03091333221122292

CROFTS, R., GORDON, J. E., SANTUCCI, V. L. 2015. *Geoconservation in protected areas. Protected area governance and management*. Canberra, ANU Press, 531-568. [online] [cit. 2025-08-15]. Available at: <https://www.jstor.org/stable/j.ctt1657v5d.25>

CUNHA, S. 2018. Gastronomic tourism, a differential factor. *Millennium*, 2(5), 93-98. DOI: https://doi.org/10.29352/mill0205.09.00157

DOWLING, R. K., NEWSOME, D. 2010. *Global geotourism perspectives*. Oxford, Goodfellow Publishers.

DOWLING, R. K., NEWSOME, D. 2018. *Handbook of geotourism*. Cheltenham, Edward Elgar Publishing.

FARSANI, N. T., COELHO, C., COSTA, C. 2011. Geotourism and geoparks as novel strategies for socio-economic development in rural areas. *International Journal of Tourism Research*, 13(1), 68-81.

FERRANDO, A., FACCINI, F., PALIAGA, G., CORATZA, P. 2021. A quantitative GIS and AHP-based analysis for geodiversity assessment and mapping. *Sustainability*, 13(18), 1-18. DOI: https://doi.org/10.3390/su131810376

FONT, X., TRIBE, J. 2000. *Forest tourism and recreation: Case studies in environmental management*. Liverpool, CABI, 1-22. DOI: https://doi.org/10.1079/9780851994147.0000

FORTE, J. P., BRILHA, J., PEREIRA, D. I., NOLASCO, M. 2018. Kernel density applied to the quantitative assessment of geodiversity. *Geoheritage*, 10, 205-217. DOI: https://doi.org/10.1007/s12371-018-0282-3

GRAY, M. 2008. Geodiversity: developing the paradigm. *Proceedings of the Geologists' Association*, 119(3-4), 287-298. DOI: https://doi.org/10.1016/S0016-7878(08)80307-0

GRAY, M. 2019. Geodiversity, geoheritage and geoconservation for society. *International Journal of Geoheritage and Parks*, 7(4), 226-236. DOI: https://doi.org/10.1016/j.ijgeop.2019.11.001

HELGADÓTTIR, G., SIGURÐARDÓTTIR, I. 2008. Horse-based tourism: community, quality, and disinterest in economic value. *Scandinavian Journal of Hospitality and Tourism*, 8(2), 105-121. DOI: https://doi.org/10.1080/15022250802088149

HJORT, J., GORDON, J. E., GRAY, M., HUNTER, M. L. 2015. Why geodiversity matters in valuing nature's stage. *Conservation Biology*, 29(3), 630-639. DOI: https://doi.org/10.1111/cobi.12510

HOSE, T. A. 2012. Editorial: Geotourism and geoconservation. *Geoheritage*, 4(1-2), 1-5.

HOSE, T. A. 2016. *Geoheritage and geotourism: A European perspective*. Woodbridge, Boydell Press. Boydell and Brewer.

JASIEWICZ, J., STEPINSKI, T. F. 2013. Geomorphons – a pattern recognition approach to classification and mapping of landforms. *Geomorphology*, 182, 147-156. DOI: https://doi.org/10.1016/j.geomorph.2012.11.005

KAUR, G. 2022. Geodiversity, geoheritage and geoconservation: a global perspective. *Journal of the Geological Society of India*, 98(9), 1221-1228. DOI: https://doi.org/10.1007/s12594-022-2156-1

KELEMEN, A. 1986. *Štiavnické vrchy*. Bratislava, Šport.

KIM, G., DUFFY, L. N., MOORE, D. 2020. Tourist attractiveness: measuring residents' perception of tourists. *Journal of Sustainable Tourism*, 28(6), 898-916. DOI: https://doi.org/10.1080/09669582.2019.1708919

KOLLÁR, D., LACIKA, J. 2004. *Štiavnické vrchy*. Bratislava, Dajama. [online] [cit. 2025-08-15]. Available at: <https://dajamabooks.sk/produkt/the-stiavnicke-vrchy-mts/>

KONEČNÝ, V., PACHINGER, P. 2023. *Geotopes of the Banská Štiavnica Geopark: volcanism and structure of the territory*. Banská Bystrica, Slovak Environment Agency. [online] [cit. 2025-08-15]. Available at: <https://www.sazp.sk/dokument/f/geotopes-of-the-banska-stiavnica-geopark-volcanism-and-structure-of-the-territory.pdf>

KUBALÍKOVÁ, L. 2013. Geomorphosite assessment for geotourism purposes. *Czech Journal of Tourism*, 2(2), 80-104. DOI: https://doi.org/10.2478/cjot-2013-0005

LESNÍCKE ARBORÉTUM KYSIHÝBEĽ 2022. *Lesnícke arborétum Kysihýbeľ*. [online] [cit. 2025-08-15]. Available at: <https://www.lesy.sk/lesy/verejnost/vyznamne-lesnicke-miesta/zoznam/lesnicke-arboretum-kysihybel.html>

LIKHACHEVA, E. A., TIMOFEEV, D. A. 2002. *Human life environment landscape. Environmental geomorphology*. Moscow, MediaPress.

MAZÚR, E., LUKNIŠ M., BALATKA B., LOUČKOVÁ J., SLÁDEK J. 1986. *Geomorphological zoning of the Slovak Socialist Republic and the Czech Socialist Republic*. Bratislava, Slovenská kartografia.

MICIĆ PONJIGER, T., LUKIĆ, T., VASILJEVIĆ, Đ. A., HOSE, T. A., BASARIN, B., MARKOVIĆ, S. B., BLEŠIĆ, I. 2021. Quantitative geodiversity assessment of the Fruška Gora Mt.(North Serbia) by using the geodiversity index. *Geoheritage*, 13(3), 1-12. DOI: https://doi.org/10.1007/s12371-021-00572-w

MUCIVUNA, V. C., REYNARD, E., GARCIA, M. G. M. 2019. Geomorphosites assessment methods: comparative analysis and typology. *Geoheritage*, 11, 1799–1815. DOI: https://doi.org/10.1007/s12371-019-00394-x

NAJWER, A., JANKOWSKI, P., NIESTEROWICZ, J., ZWOLIŃSKI, Z. 2022. Geodiversity assessment with global and local spatial multicriteria analysis. *International Journal of Applied Earth Observation and Geoinformation*, 107, 1-14. DOI: https://doi.org/10.1016/j.jag.2021.102665

NEWSOME, D., LADD, P. 2022. The dimensions of geotourism with a spotlight on geodiversity in a subdued landscape. *International Journal of Geoheritage and Parks*, 10(3), 351-366. DOI: https://doi.org/10.1016/j.ijgeop.2022.06.001

NEWSOME, D., DOWLING, R. K. 2010. *Geotourism: The tourism of geology and landscape*. Oxford, Goodfellow Publishers.

ÓLAFSDÓTTIR, R., DOWLING, R. 2014. Geotourism and geoparks – A tool for geoconservation and rural development in vulnerable Arctic environments: A case study from Iceland. *Geoheritage*, 6(1), 71-87.

ÓLAFSDÓTTIR, R., TVERIJONAITE, E. 2018. Geotourism: A systematic literature review. *Geosciences*, 8(7), 234.

PANIZZA, M., PIACENTE, S. 2009. Cultural geomorphology and geodiversity. In: Reynard, E., Coratza, P., Regolini-Bissig, G. (eds.) *Geomorphosites*, 35-48. [online] [cit. 2025-08-20]. Available at: <https://www.researchgate.net/profile/Mario-Panizza-2/publication/266021139_Cultural_geomorphology_and_geodiversity/links/59a285e70f7e9b0fb8a94f6d/Cultural-geomorphology-and-geodiversity.pdf>

PARDO-IGÚZQUIZA, E., DOWD, P. A. 2021. The mapping of closed depressions and their contribution to the geodiversity inventory. *International Journal of Geoheritage and Parks*, 9(4), 480-495. DOI: https://doi.org/10.1016/j.ijgeop.2021.11.007

PELLITERO, R., MANOSSO, F. C., SERRANO, E. 2015. Mid- and large-scale geodiversity calculation in Fuentes Carrionas (NW Spain) and Serra do Cadeado (Paraná, Brazil): methodology and application for land management. *Geografiska Annaler: Series A, Physical Geography*, 97(2), 219-235. DOI: https://doi.org/10.1111/geoa.12057

PEREIRA, P., PEREIRA, D., CAETANO ALVES, M. I. 2007. Geomorphosite assessment in Montesinho Natural Park (Portugal). *Geographica Helvetica*, 62(3), 159-168. DOI: https://doi.org/10.5194/gh-62-159-2007

PETRIȘOR, A. I., SÂRBU, C. N. 2010. Dynamics of geodiversity and eco-diversity in territorial systems. *Journal of Urban and Regional Analysis*, 2(1), 61-70. DOI: https://doi.org/10.37043/JURA.2010.2.1.4

PIACENTE, S. 2005. Geosites and geodiversity for a cultural approach to geology. *Il Quaternario*, 18(1), 11-14. [online] [cit. 2025-08-15]. Available at: <https://web.archive.org/web/20180429132931id_/http://www.aiqua.it/index.php/volume-18-1/300-geosites-and-geodiversity-for-a-cultural-approach-to-geology/file>

PRALONG, J. P. 2005. A method for assessing tourist potential and the use of geomorphological sites. *Géomorphologie: Relief, Processus, Environnement*, 11(3), 189-196. DOI: https://doi.org/10.4000/geomorphologie.350

SERRANO, E., RUIZ-FLAÑO, P. 2007. Geodiversity: a theoretical and applied concept. *Geographica helvetica*, 62(3), 140-147. DOI: https://doi.org/10.5194/gh-62-140-2007

STEPINSKI, T. F., JASIEWICZ, J. 2011. Geomorphons – a new approach to classification of landforms. *Proceedings of geomorphometry*, 109-112. [online] [cit. 2025-08-15]. Available at: <https://www.researchgate.net/profile/JaroslawJasiewicz/publication/264850233_Geomorphons__A_new_approach_to_classification_of_landforms/links/5639134508aecf1d92a9bd24/Geomorphons-A-new-approach-to-classification-of-landforms.pdf>

ŠTRBA, L., RYBÁR, P., BALÁŽ, B., MOLOKÁČ, M., HVIZDÁK, L., KRŠÁK, B., LUKÁČ, M., MUCHOVÁ, L., TOMETZOVÁ, D., FERENČÍKOVÁ, J. 2015. Geosite assessments: Comparison of methods and results. *Current Issues in Tourism*, 18(5), 496-510. DOI: https://doi.org/10.1080/13683500.2014.882885

DE TARSO CASTRO, P., MANSUR, K. L., RUCHKYS, Ú. A., IMBERNON, R. A. L. 2021. Geoethics and geoconservation: integrated approaches. *Journal of the Geological Survey of Brazil*, 4(SI1). DOI: https://doi.org/10.29396/jgsb.2021.v4. SI1.3.

THOMAS, M. F. 2012. Geodiversity and landscape sensitivity: a geomorphological perspective. *Scottish Geographical Journal*, 128(3-4), 195-210. DOI: https://doi.org/10.1080/14702541.2012.725863

TROFIMOVA, E. V. 2012. Ecologic-geomorphologic analysis of karst caves (Irkutsk amphitheatre as an example). *Geomorfology*, 2, 26-33. DOI: https://doi.org/10.15356/0435-4281-2012-2-26-33
VERNHAM, G., BAILEY, J. J., CHASE, J. M., HJORT, J., FIELD, R., SCHRODT, F. 2023. Understanding trait diversity: the role of geodiversity. *Trends in Ecology and Evolution*, 38(8), 736-748. DOI: https://doi.org/10.1016/j.tree.2023.02.010
WOLNIEWICZ, P. 2021. Beyond geodiversity sites: exploring the educational potential of widespread geological features (rocks, minerals, and fossils). *Geoheritage*, 13(2), 34. DOI: https://doi.org/10.1007/s12371-021-00557-9
ZHYRNOV, P. 2015. Geomorphosite assessment method of karst landscapes by considering the geomorphological factors. *Geomorphologia Slovaca et Bohemica*, 2, 7-19. [online] [cit. 2025-08-16]. Available at: <http://www.asg.sav.sk/gfsb/v0152/gfsb0150201.pdf>
ZWOLIŃSKI, Z. 2009. The routine of landform geodiversity map design for the Polish Carpathian Mts. *Landform Analysis*, 11, 77-85. [online] [cit. 2025-08-15]. Available at: <https://yadda.icm.edu.pl/baztech/element/bwmeta1.element.baztech-article-BUJ5-0052-0094? q=bwmeta1.element.baztech-volume-1429-799X-landform_analysis-2009-vol__11; 8 andqt=CHILDREN-STATELESS>
ZWOLIŃSKI, Z., NAJWER, A., GIARDINO, M. 2018. *Methods for assessing geodiversity*. Amsterdam, Elsevier, 27-52. DOI: https://doi.org/10.1016/B978-0-12-809531-7.00002-2

Hodnotenie geodiverzity ako počiatočný krok pri identifikácii oblastí s geoturistickým potenciálom na príklade Štiavnických vrchov na Slovensku

Resumé

Článok sa zaoberá geodiverzitou pohoria Štiavnické vrchy a analyzuje priestorové rozmiestnenie geolokalít (geosites) a ich geoturistický potenciál. Autori vychádzajú z konceptu geodiverzity ako variability hornín, reliéfu, vôd, pôd a ďalších abiotických prvkov krajiny a zároveň nadväzujú na pojmy geoheritage a geoturizmus, ktoré spájajú prírodné dedičstvo s jeho spoločenským, kultúrnym a ekonomickým využitím. Cieľom článku je pomocou metódy Zwolińského (2009) vytvoriť syntetickú mapu geodiverzity Štiavnických vrchov a porovnať ju s polohou a turistickou atraktivitou geolokalít ako prvý krok k identifikácii území s vysokým geoturistickým potenciálom.

Študovaná oblasť predstavuje neogénne stratovulkánne pohorie v rámci Slovenského stredohoria, s výraznou vnútornou morfologickou a geologickou členitosťou a silne formovanou banskohistorickou krajinou okolo Banskej Štiavnice. Autori využívajú oficiálne geomorfologické členenie podľa Mazúra a kol. (1986). Geologický vývoj je spojený s rozsiahlym stratovulkánom, andezitovými prúdmi, pyroklastikami, intrúziami, hydrotermálnymi zónami a dlhodobou ťažbou polymetalických rúd. Dôležitú úlohu v krajine zohráva aj systém tajchov a bohaté kultúrne dedičstvo, ktoré vytvára priaznivé predpoklady pre geoturizmus.

Metodika geodiverzitného hodnotenia je založená na analýze piatich zložiek: komplexného morfometrického indexu (nadmorská výška, sklon, horizontálna a vertikálna členitosť), reliéfovej diverzity odvodeného pomocou geomorfónov, geologickej diverzity, diverzity krajinnej pokrývky a diverzity pôd. Východiskom je digitálny model reliéfu s rozlíšením 10 m, pričom územie je rozdelené na sieť štvorcov 100 × 100 m; každému štvorcu sa priraďujú hodnoty z jednotlivých vrstiev a výsledný index geodiverzity je priemerom piatich normalizovaných indexov. Hodnoty sú rozdelené do piatich tried od veľmi nízkej po veľmi vysokú geodiverzitu.

Súbežne je spracovaná databáza geolokalít na základe odbornej a turistickej literatúry a geologických sprievodcov, doplnená terénnym mapovaním a presným georeferencovaním. Každý geosite je hodnotený podľa šiestich kategórií (vedecká, estetická, kultúrno-historická, ekologická, socio-ekonomická, bezpečnosť a dostupnosť), pričom jednotlivé kritériá sú bodované v intervale 0 – 1. Z kategórií sa počíta syntetický index turistickej atraktivity a geosites sú zaradené do troch tried: nízka, stredná a vysoká atraktivita. Následne sa tento bodový súbor prekrýva so syntetickou mapou geodiverzity a štatisticky sa vyhodnocujú vzťahy podľa geomorfologických podcelkov.

Výsledky ukazujú, že približne dve tretiny územia Štiavnických vrchov majú vysokú až veľmi vysokú geodiverzitu, dominantná je trieda „vysoká" (57,7 % plochy). Najvyššie hodnoty sa koncentrujú v oblastiach Sitna, Hodrušskej vrchoviny a Skalky, zatiaľ čo nižšie indexy charakterizujú kotliny, brázdy a akumulačné zóny. Rozloženie geolokalít do istej miery kopíruje tieto vzorce – väčšina geosites sa nachádza v oblastiach s vysokou geodiverzitou bez ohľadu na mieru ich turistickej atraktivity. Zároveň však existujú územia s vysokou geodiverzitou, kde geolokality chýbajú alebo sú prítomné len ojedinele, najmä v severných, východných, južných a juhozápadných častiach pohoria. Naopak, v Štiavnickej brázde sa viacero geolokalít viaže na antropogénne a kultúrne prvky v prostredí nižšej prírodnej geodiverzity.

Diskusia poukazuje na to, že geodiverzita je vhodným „základným filtrom" na identifikáciu území, kde má zmysel podrobnejšie analyzovať geoturistický potenciál, ale neexistuje jednoduchá lineárna väzba medzi geodiverzitou a atraktivitou geosites. Dôležitú úlohu zohrávajú aj antropogénne prvky, dostupnosť, infraštruktúra a kultúrne kontexty. V článku sa zároveň kriticky reflektujú limity použitej metodiky (napr. potenciálne prekrývanie informácie z vrstiev pôd a krajinnej pokrývky či rovnaké váženie všetkých komponentov) a navrhujú, že v budúcnosti by bolo možné uplatniť diferencované váhy alebo doplniť ďalšie ukazovatele.

V závere článku sa zdôrazňuje, že syntetická mapa geodiverzity Štiavnických vrchov predstavuje dôležitý podklad pre plánovanie geoturizmu, geoochranárske opatrenia a udržateľné využívanie územia. Ukazuje nielen jadrové oblasti s vysokou geodiverzitou a vysokou koncentráciou geolokalít, ktoré si vyžadujú citlivú ochranu, ale aj „biele miesta" – geodiverzitou bohaté zóny s chýbajúcou turistickou ponukou, kde možno cielene rozvíjať nové geoturistické produkty (napr. lesnícke arboretá, tematické trasy, malé múzeá či prírode blízke rekreačné aktivity) pri rešpektovaní princípov geoetiky a udržateľnosti.