Bulletin of Natural Sciences Research
Vol. 14, No. 1-2, 2024. pp. 26-33.

DOI: https://doi.org/10.5937/bnsr14-54328
Original Scientific Paper

THE RELATIONSHIP BETWEEN GEODIVERSITY AND BIODIVERSITY – A THEORETICAL APPROACH

MARKO IVANOVIĆ[1]

[1]Faculty of Sciences and Mathematics, University of Priština in Kosovska Mitrovica, Kosovska Mitrovica, Serbia

ABSTRACT

The relationship between geodiversity and biodiversity is often considered within geoecological frameworks. Their interaction within real space forms the natural structure of landscapes. Although they are defined as two separate and equivalent systems with different structures, their relationship makes them interdependent, with geospatial distribution being the common point of contact. The term "geodiversity" is relatively recent, defined as the desire to express the opponent of the diversity of the living world – biodiversity. Thus, through a holistic concept, it is possible to observe multiple levels of interaction between geodiversity and biotic resources, revealing their interrelationship. The challenges of researching both geodiversity and biodiversity are characterized by similar shortcomings. Based on the previous researches of different authors, the work aims to define in the best possible way a biotic-abiotic relationship as an essential component in the concept of nature, the sphere of their connection and joint action. However, due to the numerous fields of their interaction, the work only partially defines them, without analyzing each field of interaction, in detail. In addition, the connection of these two concepts also requires interdisciplinary cooperation, the goal of which must be to improve the understanding of biodiversity and geodiversity, and their integration in evaluation, with the common goal of protecting and preserving nature as a whole and its individual parts. To a significant extent, these can be addressed through the application of geoinformatics tools, methods, and techniques, especially Remote Sensing (RS) and Geographic Information Systems (GIS), which offer the possibility of more adequate evaluation and interpretation of results.

Keywords: Geodiversity, Biodiversity, Connection, Interaction, Remote Sensing, GIS.

INTRODUCTION

Viewed through the lens of the holistic principle, the natural structure of the landscape can be characterized as an interaction between geodiversity and biodiversity. The general and most commonly cited opinion defining the relationship between geodiversity and biodiversity is that basically, geodiversity is often considered abiotic equivalent to biodiversity (Croft & Gordon, 2014). Geodiversity is the abiotic foundation or basis for the existing biodiversity, including humans, with abiotic elements providing the foundation for living nature by creating variations such as topographic and climatic conditions (Grey, 2013). According to Lješević (2002), the structural and quantitative-qualitative characteristics of biodiversity are largely in dependent relationships with the characteristics, i.e., the vertical structure of geodiversity, upon the basis of which biodiversity was built. The holistic approach involves viewing the natural environment as a whole rather than just its individual parts. Observing the natural environment through the lens of holism allows us to define and comprehensively understand geodiversity both within its internal structure and through its interaction with biodiversity.

Remote Sensing (RS) and Geographic Information Systems (GIS) are becoming powerful tools (Hrnjak et al., 2014) for inputting, editing, analyzing, creating, and improving spatial data (Ivanović et al., 2023). Their multiplicity has been proven in numerous studies from various scientific fields of biological and geographical sciences. They can be a means to complete the relationship of two entities, within the natural structure of the landscape with protection and conservation as a common primary goal.

BIODIVERSITY AND GEODIVERSITY- HISTORY OF DEFINING THE TERMS

Originally, the concept "diversity" almost exclusively referred to biological diversity - biodiversity. As a term, it was first proposed in 1974 and scientifically established in 1980. It was internationally recognized only in 1992, as a term encompassing the conservation of the biosphere. At the United Nations Conference on Environment and Development in Rio de Janeiro, the Convention on Biological Diversity was defined. Represent a binding agreement on the inventory of plant and animal life, especially endangered species and those on the verge of extinction (Milentijević, 2021). On that occasion, the term "biodiversity" was defined as "the variability among living organisms from all sources, including, inter alia, terrestrial, marine, and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species, and of ecosystems" (United Nations, 1993). At that time, great attention was given to protection on international, national, regional, and local

* Corresponding author: marko.ivanovic@pr.ac.rs

levels, as well as to increasing the biological diversity of planet Earth. In the following years, many countries created their own national plans for the protection and conservation of ecosystems and habitats of plant and animal species, their monitoring and sustainable management strategies are crucial. Biodiversity is classified at different levels- such as genetic diversity (preservation of the gene pool), species diversity (reduction or loss of species), and ecosystem diversity (maintenance and enhancement of habitats and their biological systems). However, since biodiversity does not represent just the number of species or ecosystems, but also refers to the countless interconnections between them (Grey, 2004), such views led to subsequent UN-sponsored conferences that more precisely defined biodiversity within specific types of ecosystems. Since then, more than 100 books have been published with "biodiversity" in the title, and E.O. Wilson, often known as the father of biology, has stated that this term poses some of the most fundamental problems in biological science (Grey, 2023).

As a result of the aforementioned conference about the environment in Rio de Janeiro, the term "geological and geomorphological diversity" increasingly appeared in geographic scientific literature, primarily as a "natural equivalent (twin) to the term 'biodiversity" (Grey, 2004; Grey, 2008a; Grey, 2008b). It is difficult to determine when exactly this term started being used or who first coined it, but the year 1993 is often cited in the literature as pivotal in the use of the term "geodiversity." The publicity given to the concept of biodiversity at this conference attracted the attention of geographers to also study the diversity of geographical phenomena on our planet. Not long after, within a short period of time and independently of each other numerous geographers coined the term "geodiversity", making its (scientific) introduction become almost unavoidable (Grey, 2018).

According to Grey (2008a), the term "geodiversity" was first used in scientific publications in Germany and Australia. At the Malvern Conference (England) in 1993, Wiedenbein (1994) introduced the term, which is believed to have already been used within geological and geoecological contexts in German-speaking regions. Similar terminologies had been used much earlier within the Australian geological school. In the following years, in both European and Australian contexts, the definition of the term "geodiversity" became closely tied to its protection. Authors Serrano & Ruiz-Flaño (2007), note that the term "geodiversity" was actually conceived as early as the 1940s by Argentine geographer Federico Alberto Daus to describe "the mosaic of landscapes and cultural diversity of geographical space, and territorial complexity at different scales (locality, district, and region) related to human habitats" within the context of cultural geography. They also highlight that since the 1990s, the naturalistic concept of defining the term has prevailed. The concept of geodiversity was quickly accepted globally and emerged from the desire to shift from the traditionally entrenched biocentric approach to environmental protection, towards a more scientifically sound holistic approach (Simić et al., 2010).

THE CONCEPT OF GEODIVERSITY

There are three main concepts related to the theory of geodiversity (Najwer & Zwolinski, 2014; Najwer et al., 2023).

Classical understandings evolved through the research work of Australian geologists and geomorphologists, which also included geoconservation (Sharples et al., 2018). In reports from commissions related to studies on the protection of areas in Tasmania and other parts of Australia, the term "geodiversity" was frequently used in publications. The term is based on previously used terminology dating back to the 1970s (such as "site", "form", "geological monument", "place", "area" and "significant geological phenomena"), which were linked to the certain features (Joyce, 2010). At that time, geologists and geomorphologists were attempting to describe the diversity of non-living nature- landform diversity or geomorphic diversity (Vasiljević, 2015) while Sharples (1993) used the term to encompass all "diversities of landforms and systems." After numerous debates and efforts to standardize terminology, several definitions of "geodiversity" emerged, with a few standing out:

- the connection between people, landscape, and culture; the diversity of geological environments, phenomena, and processes that form that landscape (relief), rocks, minerals, fossils, and soils that provided the framework for life on Earth" (Stanley, 2001);
- complex variations of rocky soil, soft sediments, landscapes, and processes that shape that landscape; the diversity of geological and geomorphological phenomena in a defined area" (Johansson, 2000).

As a result of years of continuous research on geological heritage, the Australian Heritage Commission (AHC, 2002) defines the term as "the range or diversity of geological (rocky soil), geomorphological (relief forms), and soil phenomena, structures, systems, and processes" (Gray, 2008a).

Within a second concept, geodiversity is considered the foundation for various analyses conducted on biodiversity, with the differentiation of the abiotic subsystem considered collaterally, usually as an auxiliary variable (Hjort et al., 2015; Ren et al., 2021). The third concept deviates from the classical (geological) definition of geodiversity and is characterized more broadly, including topography, elements of the hydrosphere, and human activities, among other factors (Najwer et al., 2023).

The beginning of the 21st century will mark a significant expansion in attempts to define the terminology for the study of shapes and forms, as well as the methodological evaluation of geodiversity. Authors Boothroyd & McHenry (2019) highlight that as many as 299 academic scientific articles are related to the definition and evaluation of geodiversity. Earlier works attempting to define the terminology of geodiversity were authored exclusively by geologists who focused almost entirely on geodiversity terminology in the context of geology and geomorphology. It is noted that the incompleteness of such definitions prompted considerations of a broader perspective on this complex concept, defined as "geographical diversity of landscapes, not expressed solely through geological composition and morphological elements and processes" (Novković, 2008). The term geodiversity also refers to the "surface waters, as well as other systems created as a result of both natural (endogenous and exogenous) processes and human activities" (Kozlowski, 2004). Authors Simić et al. (2010), accept these ideas and expand the context of the term, defining geodiversity as "the diversity of the geographical environment, which is the result of geological, geographical, and anthropogenic influences".

The scientific debate over the definition of terminology has led to the publication of what is perhaps the most frequently cited definition. This, possibly the most holistic definition (Najwer et al., 2023), describes geodiversity as "the natural range (diversity) of geological (rocks, minerals, fossils), geomorphological (relief forms, topography, physical processes), soil, and hydrological phenomena. It also includes their compositions, structures, systems, and contributions to the landscape" (Gray, 2013). Around 88% of papers defining geodiversity, published between 1993 and 2019, support this definition or its similar variants (Boothroyd & McHenry, 2019).

Seeking to improve the definition promoted in M. Gray's works, many authors have tried to clarify certain parts of it in different contexts. In the publications of Ibañez et al. (1995) and Ibañez & Bockheim (2013), the term "pedodiversity" is emphasized as part of natural and cultural heritage. Based on earlier works, authors Panizza (2009) and Reynard et al. (2009), introduced the concepts of "geomorphodiversity" and "geomorphosite". The works of Ferrarin et al. (2014), Rosa et al. (2018), and Gil-Márquez et al. (2022), prefer the term "hydrodiversity" whose related to the natural and cultural heritage. In the work of Doherty et al. (2021), "topodiversity" is used to define topography. On the other hand, Grey (2023) views the term "geodiversity" as an abbreviation for "geoscientific diversity", considering that it encompasses not only geological phenomena but has a much broader meaning.

Considering all aspects of defining geodiversity, it can be concluded that although the pioneering interpretations of the term were linked to geological diversity. It also encompasses all geomorphological, pedological, and hydrological forms and phenomena, resulting from exogenous and endogenous forces, tectonic processes as well as hydrological (hydrogeological) phenomena and processes. In some scientific perspectives, this term also includes climatic processes and specificities. Regarding the Republic of Serbia, the Low on Environmental Protection of 2021 (Official Gazette of the RS, 71/2021), defines the term "geodiversity" at first as "geological diversity“ and as the presence or distribution of diverse elements and forms of geological structures, geological formations and processes, geochronological units, rocks, and minerals of various compositions and origins, and diverse paleoecosystems changed in space under the influence of internal and external geodynamic factors during geological time.

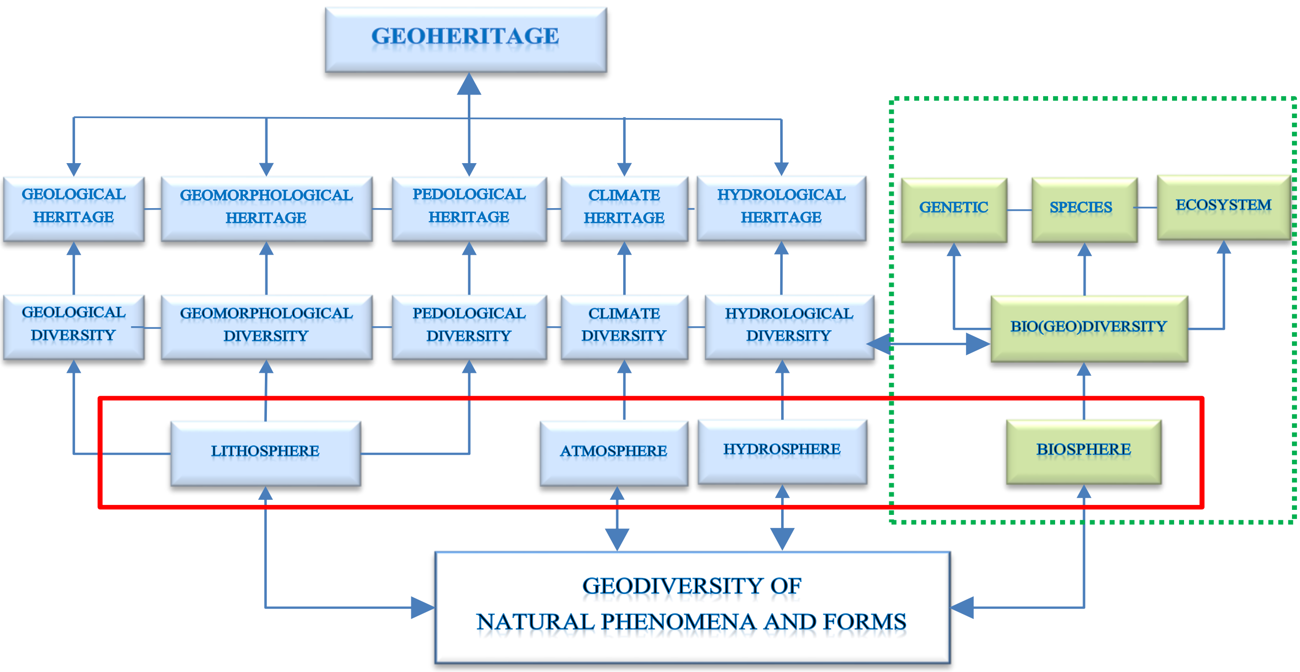

Figure 1. Schematic representation of the relationship between geodiversity and biodiversity (based on Simić et al., 2010; Miljković, 2018).

Following the holistic approach of a unified, mutually dependent system of "bio-geo-diversity," discussions about the subject of research have evolved. According to Lješević (2002), geodiversity consists of two major components: the geodiversity of natural phenomena and forms, and the geodiversity of civilization. The geodiversity of natural phenomena and forms (Figure 1) is of interest to experts in the Earth sciences. It is represented by geological diversity, geomorphological diversity, climatic diversity, hydrological diversity, soil diversity, and bio-geo-diversity.

SYSTEMIC RELATIONSHIP BETWEEN GEODIVERSITY AND BIODIVERSITY

The overall relationship between bio- and geo-diversity can be viewed through two categories (levels) of relationships. The first category focuses on the theoretical approach to interaction, defined through fields of overlap and joint action in the natural environment. Santucci (2005) considers that bio- and geo-diversity overlap and cites several areas of influence where geological resources and geodiversity impact biotic resources, which illustrates the full meaning of their mutual interconnection, with which Vasiljević (2015) also agreed:

- **Climate-** Climatic elements can influence the morphology of geological forms and the intensity of processes at a local level. Precipitation and temperature can affect certain processes (erosion, denudation, rock decomposition, etc.);
- **Hydrology-** The hydrology of geospace is largely conditioned by geological and geomorphological characteristics. Drainage areas, watersheds, aquifers, springs related to lithographic and stratigraphic contacts, and geomorphological features, such as karst topography, periglacial zones, and landslides, are examples. Biodiversity can also be influenced by water's chemical properties, salinity, and other hydrological features;
- **Soil-** Soil serves as the link between the abiotic and biotic world. Its composition and chemical properties are directly connected to the bedrock. Consequently, the distribution of many plant species depends on the mineralogical and chemical composition of the soil;
- **Biogeographical Distribution-** The geographical distribution of the ranges of flora and fauna can often be linked to geodiversity. Surface geomorphology frequently influences geographical distribution and migration routes. Mountain ranges, canyons, deserts, and water bodies are just some geological forms that can act as migration corridors but also as barriers;
- **Habitats-** The diversity of geological characteristics and processes provides an almost infinite range of habitat types for sustaining life. Changes in elevation between intermontane basins and mountain ranges typically encompass multiple life zones. Geothermal springs provide the nutrients and temperature necessary for certain bacterial forms. Cave openings, sloping landslides, and gypsum sand offer habitats for species adapted to these environments.

Altitude and the topographic characteristics of a geospace can significantly impact its biodiversity. Altitude greatly influences climatic conditions, and together with topographic features, it can significantly affect the hydrological parameters of an area and changes in soil cover. It is known that changes in altitude affect the ranges of flora and fauna, creating specific habitats.

In line with this, when discussing the overlap of two equivalent systems, it can be concluded that spatial distribution is the point of interaction where the two systems overlap. It is a fact that biodiversity and geodiversity represent individual systems, while their point of contact is defined solely through the spatial diversity and distribution of biodiversity, and only then can biodiversity be considered as part of geodiversity (Lješević, 2002). However, spatial distribution can be reflected on two levels. Horizontal spatial distribution refers to the area as a geographical surface- the territory it occupies. Under the influence of altitude, ranges can shift or change, which allows us to speak of spatial distribution in a vertical sense.

The difference in complexity is reflected on multiple levels. Often, the number of geodiversity elements in a given area is much greater than the number of plant species, with some geodiversity elements varying in composition (type) as well as in the percentage of participation of those types. Classification issues also arise, even though "international and national classifications exist" (Gray, 2023). Authors Ibáñez & Brevik (2022), are among the scientists who identify the problem of classification in geodiversity research, emphasizing that "unlike biodiversity and soil diversity, there is no universal classification in lithology and geomorphology" and that "studies dealing with geodiversity do not pay much scientific attention to the analysis and quantification of Earth's surface systems, as is the case in biodiversity studies".

The second category of relations is related to the practical approach. It implies the creation of common methods and techniques for conducting research, analysis and evaluation within the common framework of the geoecological context. The common goal of research and evaluation of both geodiversity and biodiversity is protection and conservation. Geodiversity has an important ecological value in supporting biodiversity and ecosystem functioning so the conservation of geosites and geodiversity has a fundamental role in preserving protected areas as an integral part of nature and natural heritage. Consequently, geoconservation is crucial for sustaining living species and habitats, both to maintain the abiotic setting or 'stage' and the natural processes (e.g. floods, erosion and deposition) necessary for habitat diversity and ecological functions (Croft, 2019).

Authors Zwolinski et al. (2018), explain that the evaluation process begins with classification, i.e., identifying individual entities or phenomena, followed by the selection of criteria that influence the choice of method and the selection of materials- information or digital data. So far, the methodological intentions of scholars have focused on evaluating geodiversity independently, irrespective of biodiversity (Tukiainen et al., 2023). A similar approach is taken from the aspect of biodiversity valuation, in which spatial distribution is taken into account and, to a very small extent, geodiversity as a key basis.

This also initiates the issue of measurement since, although geodiversity represents the totality of the abiotic nature of an area, measuring the overall wealth can be extremely difficult and time-consuming. As a result, measurements are often focused on studying geological, topographical, hydrological, pedological, and/or satellite imagery in smaller areas (Gray, 2023). Measurements may also pertain to geomorphological and climatic phenomena and forms that can be considered parts of geodiversity.

The assessment of geodiversity can be qualitative (descriptive methods), quantitative (valuation of geodiversity indices, metrics or statistical modeling) or qualitative–quantitative (combination of quantitative (i.e., digital) data and cause-effect (i.e., relational and explanatory) data (Zwoliński et al., 2018). However, in a review of quantitative geodiversity assessment Crisp et al. (2021), found that half of 534 publications assessed geodiversity independently, and only 12% of them strongly linked biodiversity to geodiversity. The remaining one-third of the reviewed publications discussed or reviewed biodiversity without strong empirical objectives.

The challenges of geodiversity research are more pronounced compared to those of biodiversity research. The issue lies in the much greater complexity of geodiversity, which significantly affects the challenges of assessing it.

Methods and techniques of RS, GIS, and the application of Digital Elevation Models (DEM), play a significant role in assessing geodiversity, providing opportunities for substantial revision of methodologies (Stojilković, 2022). Therefore, the use of geoinformatics tools, methods, and techniques can significantly address the challenges of researching both geodiversity and biodiversity, improving measurement, evaluation, and interpretation of results. GIS systems have the capability of storing large quantities of spatiotemporal data, enabled by advances in computing and geoinformation technologies. Automated algorithmic software processes shorten the time period, significantly enhancing the evaluation concept. The final result emphasizes the cartographic visualization of spatial distribution. This makes Geographic Information Systems (GIS) an indispensable tool in spatial visualization and analysis of results from numerous geostatistical methods in modern environmental research, even at the macro level, thus significantly mitigating research challenges.

Quantitative assessments of geodiversity can be derived from field measurements, numerical calculations or geospatial analyses of raw data (Zwoliński et al., 2018). In geodiversity–biodiversity studies, geodiversity is commonly assessed with statistical tools (Crisp et al., 2021). Different types of RS or GIS based datasets are preferred as the source of geodiversity information (Boothroyd & McHenry, 2019). For instance, the statistical Geosite Assessment Model (GAM) and GIS-based isochronous method were used for the assessment of geosites in Toplica district (Serbia) for the purpose of geotourism development (Ivanović, et al, 2023); techniques of watershed delineation and multi-criteria decision analysis (MCDA) were used for GIS and Spatial analysis of population dynamics and water stress impact on Africa's River Systems (Valjarević, 2024); GIS-based methods and RS with geostatistical method were used for identifying river network types and changing river basins border in Serbia (Valjarević, 2024). Whereas this is an example of a resource-efficient way of quantifying geodiversity and exploring geodiversity–biodiversity relationships, identifying and choosing appropriate materials and methods (for appropriate scale and for the specific objectives of each study) require constant careful consideration (Gray 2021; Tukiainen et al., 2023).

CONCLUSION

In earlier scientific studies, the terms biodiversity and geodiversity were long regarded separately, with clear distinctions between the worlds of living and non-living nature. However, observing the natural environment through the lens of holistic philosophy reveals that these two equivalents, although distinct, actually share several fields of mutual interaction. A large number of studies linking geo- and bio-diversity emphasize the positive connection between these two basic parts of nature. Improving the understanding of their connections is the task of research in several scientific disciplines, from ecology to geographic disciplines that study the Earth, the environment, and the protection and preservation of nature. However, much remains to be explored in this relatively new field of research.

The paper provides an overview and defines mutual relations on a theoretical and practical level as well as the common characteristics of these entities of nature. It also presents new methods and techniques that provide a way and a direction to fill the gaps in geodiversity and biodiversity. In this way, the joint interaction of these entities in nature would be more adequately investigated, taking into account all factors.

Geodiversity is considered the foundation on which life, including human life, rests. It does not only encompass geological diversity but is a much more complex concept that includes broader geographical and anthropogenic components. Topography and hypsometric characteristics, climatic features (especially local microclimates), hydrographic features, and soil composition, can significantly influence the biogeographical distribution of living organisms and the extent of their habitats. At the same time, biodiversity, through its presence in a geographic space, significantly contributes to the preservation of geodiversity characteristics- it optimizes climatic conditions (reducing soil temperature and preventing excessive soil drying), prevents denudation, ravines, and landslides, and reduces deflation, thereby ensuring the stability of geodiversity. Based on this view, these two equivalents can be viewed as part of the natural environment or geo-biosystem with similar research problems. Therefore, the principle of holism provides us with a way to conduct research in the natural environment, taking into account the cause-effect relationships of these equivalents.

However, the real challenge in the current geo-bio-diversity relationship is the multiplicity of ways of classifying, qualifying and measuring geodiversity. This type of problem is expressed to a lesser extent in the field of biodiversity. The concept of geodiversity is still in development, which is the reason for the absence of unique terminological and methodological definitions. In terminological frameworks in the literature, the interpretation of geodiversity as a holistic "geoscientific diversity" is often preferred. At the same time, in the more flexible qualifications of geodiversity, it increasingly approaches the geoecological and biological context by including climatic and biogeographical diversity, which significantly affects the methodological complexity and variability in scientific studies. A clear definition of terminology and concepts is the starting point for a better understanding of the relationship between geo- and biodiversity, which should be insisted upon, and what further initiates the importance of unifying and harmonizing the methodology. Unique approaches to measuring both diversities would be particularly useful for nature conservation and management. Also from the aspect of biodiversity, there is a noticeable absence of research on the connections of different groups of organisms with geodiversity, so more attention should be paid to research of that nature.

One of the ways of bridging methodological problems that would correct the gap between geodiversity and biodiversity is the application of geoinformatics methods and techniques, especially RS and GIS. Geoinformatics methods are interdisciplinary in nature, so their application has already been widely applied in numerous geographic and biological studies of evaluation and protection. The preservation and management of geodiversity and biodiversity urgently needs additional tools, the application of which can be of a global character, but which can also be used to investigate local changes. As geodiversity can be considered an initiator of biodiversity conservation, one of its advantages is the availability of data on geodiversity at different scales. While biodiversity data are globally sparse and concentrated, some geodiversity data can be relatively easily accessible through GIS databases or Remote Sensing techniques. Taking into account the meaning of geoinformatics methods and techniques, they can be a means by which the shortcomings of descriptive and statistical methods are eliminated and enable a more adequate evaluation, analysis and geo-visualization of the results.

The main change towards a better understanding of the interaction and protection of geodiversity and biodiversity must be based on more effective communication and interdisciplinary cooperation of experts, identification of common goals and joint action. Therefore, joint actions are necessary because the common interest is the preservation and protection of nature.

ACKNOWLEDGMENTS

The authors are grateful for the financial support of the Ministry of Science, Technological Development and Innovation (project no. 451-03-65/2024-03/ 200123).

REFERENCES

Australian Heritage Commission (AHC). 2002. Australian Natural Heritage Charter for the conservation of places of natural heritage significance. Canberra: Commonwealth of Australia, 2nd ed.

Boothroyd, A. & McHenry, M. 2019. Old processes, new movements: the inclusion of geodiversity in biological and ecological discourse. Diversity, 11(11), 216. https://doi.org/10.3390/d11110216

Crisp, J. R., Ellison, J. C. & Fischer, A. 2021. Current trends and future directions in quantitative geodiversity assessment. Progress in Physical Geography: Earth and Environment, 45, pp. 514-540. https://doi.org/10.1177/0309133320967219

Crofts, R. & Gordon, J. E. 2014. Geoheritage conservation in protected areas. Parks, 20(2), pp. 61-76. http://dx.doi.org/10.2305/IUCN.CH.2014.PARKS-20-2.RC.en

Crofts, R. 2019. Linking geoconservation with biodiversity conservation in protected areas. International Journal of Geoheritage and Parks, 7(4), pp. 211-217. https://doi.org/10.1016/j.ijgeop.2019.12.002

Doherty, K. D., Kuhlman, M. P., Durham, R. A., Ramsey, P. W. & Mummey, D. L. 2021. Fine-grained topographic diversity data improve site prioritization outcomes for bees. Ecological Indicators, 132, 108315. https://doi.org/10.1016/j.ecolind.2021.108315

Ferrarin, C., Bajo, M., Bellafiore, D., Cucco, A., De Pascalis, F., Ghezzo, M. & Umgiesser, G. 2014. Toward homogenization of Mediterranean lagoons and their loss of hydrodiversity. Geophysical Research Letters, 41(16), pp. 5935-5941. https://doi.org/10.1002/2014GL060843

Gil-Márquez, J. M., Andreo, B. & Mudarra, M. 2022. Studying hydrogeochemical processes to understand hydrodiversity and the related natural and cultural heritage.

The case of Los Hoyos area (South Spain). Catena, 216, B, 106422. https://doi.org/10.1016/j.catena.2022.106422
Gray, M. 2004. Defining Geodiversity. In: Geodiversity: Valuing and Conserving Abiotic Nature: John Wiley & Sons, Chichester, UK. 2004; pp. 1-9.
Gray, M. 2008a. Geodiversity: developing the paradigm. Proceedings of the Geologists' Association, 119, pp. 287-298. https://doi.org/10.1016/S0016-7878(08)80307-0
Gray, M. 2008b. Geodiversity: A new paradigm for valuing and conserving geoheritage: Geoscience Canada, 35, 2, pp. 51-59. https://id.erudit.org/iderudit/geocan35_2ser01
Gray, M. 2013. Geodiversity: valuing and conserving abiotic nature: John Wiley & Sons, Chichester, UK, 2nd edition.
Gray, M. 2018. Geodiversity: the backbone of geoheritage and geoconservation. In: Geoheritage, pp. 13-25. https://doi.org/10.1016/B978-0-12-809531-7.00001-0
Gray, M. 2021. Geodiversity: a significant, multi-faceted and evolving, geoscientific paradigm rather than a redundant term. Proceedings of the Geologists' Association, 132, pp. 605-619. https://doi.org/10.1016/j.pgeola.2021.09.001
Gray, M. 2023. Some observations and reflections on geodiversity, the oft-forgotten half of nature. In: Kubalíková, L., Coratza, P., Pál, M., Zwoliński, Z., Irapta, P. N. & van Wyk de Vries, B. (eds). Visages of Geodiversity and Geoheritage. Special Publications: Geological Society, London, 530, pp. 31-47. https://doi.org/10.1144/SP530-2022-100
Kozlowski, S. 2004. Geodiversity. The concept and scope of geodiversity. Polish geological review (Przeglad geologiczny), 52(8/2), pp. 833-839.
Hjort, J., Gordon, J. E., Gray, M. & Hunter, M. L. 2015. Why geodiversity matters in valuing nature's stage. Conservation Biology, 29, pp. 630-639. https://doi.org/10.1111/cobi.12510
Hrnjak, I., Lukić, T., Gavrilov, M., Marković, S., Unkašević, M. & Tošić, I. 2014. Aridity in Vojvodina, Serbia. Theor Appl Climatol. 115, pp. 323-332. https://doi.org/10.1007/s00704-013-0893-1
Ibañez, J. J., De-Albs, S., Bermúdez, F. F. & García-Álvarez, A. 1995. Pedodiversity: concepts and measures. Catena, 24(3), pp. 215-232. https://doi.org/10.1016/0341-8162(95)00028-Q
Ibáñez, J. J. & Bockheim, J. G. 2013. Pedodiversity: CRC Press.
Ibáñez, J. J. & Brevik, E. C. 2022. Geodiversity research at the crossroads: two sides of the same coin. Spanish Journal of Soil Science, 12, 10456. https://doi.org/10.3389/sjss.2022.10456
Ivanović, M., Lukić, T., Milentijević, N., Bojović, V. & Valjarević, A. 2023. Assessment of geosites as a basis for geotourism development: A case study of the Toplica District, Serbia. Open Geosciences, 15(1), 20220589. https://doi.org/10.1515/geo-2022-0589
Johansson, C. E. 2000. Geodiversitet i Nordisk Naturvard: Nordisk Ministerr˚aad, Copenhagen.
Joyce, E. B. 2010. Australia's geoheritage: history of study, a new inventory of geosites and applications to geotourism and geoparks. Geoheritage, 2, pp. 39-56. https://doi.org/10.1007/s12371-010-0011-z
Lješević, M. A. 2002. Geodiversity as a condition of the environment, Collection of Papers Faculty of Geography at the University of Belgrade, 50, pp. 17-32.
Najwer, A. & Zwoliński, Z. 2014. Semantyka i metodyka oceny georóżnorodności – przegląd i propozycja badawcza. Landform Analysis, 26, pp. 115-127. http://dx.doi.org/10.12657%2Flandfana.026.011
Najwer, A., Reynard, E. & Zwoliński, Z. 2023. Geodiversity assessment for geomorphosites management: Derborence and Illgraben, Swiss Alps: Geological Society, London, Special Publications, 530, 1, pp. 89-106. https://doi.org/10.1144/SP530-2022-122
Novković, I. 2008. Geoharitage of Zlatibor district: Zaštita prirode, 58(1-2), pp. 37-52.
Milentijević, N. 2021. Vrednovanje geoekoloških determinanti Bačke u funkciji održivog razvoja. Doctoral dissertation, University of Novi Sad (Serbia).
Miljković, Đ. 2018. Geomorfološko i hidrološko geonasleđe Homolja. Doctoral dissertation, University of Novi Sad (Serbia).
Official Gazette of the RS (No. 36/2009, 88/2010, 91/2010 - correct, 14/2016, 95/2018 – and other, 71/2021). https://www.paragraf.rs/propisi/zakon_o_zastiti_prirode.html Accessed: 31.11.2024.
Panizza, M. 2009. The geomorphodiversity of the Dolomites (Italy): a key of geoheritage assessment. Geoheritage, 1(1), pp. 33-42. https://doi.org/10.1007/s12371-009-0003-z
Ren, Y., Lü, Y., Hu, J. & Yin, L. 2021. Geodiversity underpins biodiversity but the relations can be complex: implications from two biodiversity proxies. Global Ecology and Conservation, 31, e01830. https://doi.org/10.1016/j.gecco.2021.e01830
Reynard, E., Coratza P. & Regolini-Bissig. 2009. Geomorphosites: Verlag Dr. Friedrich Pfeil, München.
Rosa, E., Dallaire, P. L., Nadeau, S., Cloutier, V., Veillette, J., van Bellen, S. & Larocque, M. 2018. A graphical approach for documenting peatland hydrodiversity and orienting land management strategies. Hydrological Processes, 32(7), pp. 873-890. https://doi.org/10.1002/hyp.11457
Serrano, E. & Ruiz-Flaño, P. 2007. Geodiversity: a theoretical and applied concept. Geographica Helvetica, 62(3), pp. 140-147. https://doi.org/10.5194/gh-62-140-2007
Sharples, C. 1993. A Methodology for the Identification of Significant Landforms and Geological Sites for

Geoconservation Purposes: Forestry Commission, Tasmania.
Sharples, C., McIntosh, P. & Comfort, M. 2018. Geodiversity and geoconservation in land management in Tasmania- a top-down approach. In: Reynard, E. and Brilha, J. (eds) Geoheritage: Assessment, Protection, and Management:, pp. 355-371. Elsevier. https://doi.org/10.1016/B978-0-12-809531-7.00020-4
Simić, S., Gavrilović, Lj. & Đurović, P. 2010a. Geodiversity and geoheritage: a new approach to the interpretation of the terms: Bulletin of the Serbian Geographical Society, 90(2), pp. 1-14.
Stanley, M. 2001. Welcome to the 21st century: Editorial. Geodiversity Update, 1, 1.
Stojilković, B. 2022. Towards transferable use of terrain ruggedness component in the geodiversity index. Resources, 11(2), 22. https://doi.org/10.3390/resources11020022
Tukiainen, H., Toivanen, M. & Maliniemi, T. 2023. Geodiversity and biodiversity . In: Kubalíková, L., Coratza, P., Pál, M., Zwoliński, Z., Irapta, P. N. and van Wyk de Vries, B. (eds). Visages of Geodiversity and Geoheritage. Geological Society, London, Special Publications, 530, pp. 31-47. https://doi.org/10.1144/SP530-2022-107
United Nations. 1993. Report of the United Nations Conference on Environment and Development, Rio de Janeiro, 3-14 June 1992: United Nations, New York.
Valjarević, A. 2024. Population Dynamics and Water Stress: Analyzing Impacts on Africa's River Systems Through GIS and Spatial Analysis. Available at SSRN http://dx.doi.org/10.2139/ssrn.5010532
Valjarević, A. 2024. GIS-Based Methods for Identifying River Networks Types and Changing River Basins. Water Resources Management, pp. 1-19. https://doi.org/10.1007/s11269-024-03916-7
Vasiljević, Đ. A. 2015. Geodiverzitet i geonasleđe Vojvodine u funkciji zaštite i turizma. Doctoral dissertation, University of Novi Sad (Serbia).
Wiedenbein, F.W. 1994. Origin and use of the term 'geotope' in German-speaking countries. In: O'Halloran, D., Green, C., Harley, M., Stanley, M. & Knill, J. (eds) Geological and Landscape Conservation: Geological Society, London, pp. 117-120.
Zwoliński, Z., Najwer, A., & Giardino, M. 2018. Methods for assessing geodiversity. In: Reynard, E. & Brilha, J. Geoheritage: Assessment, Protection and Management, 1st edition: Elsevier, Amsterdam, pp. 27-52. https://doi.org/10.1016/B978-0-12-809531-7.00002-2