Nativa, Sinop, v. 13, n. 2, p. 266-276, 2025.
Pesquisas Agrárias e Ambientais
DOI: https://doi.org/10.31413/nat.v13i2.19292
ISSN: 2318-7670

A decade of scientific production on water quality: a bibliometric analysis of regional perspectives in Brazil and Hungary (2015-2024)

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Submitted: 03/08/2025; Accepted: 05/08/2025; Published: 05/23/2025.

ABSTRACT: This paper performs a bibliometric analysis on water quality scientific production in Brazil and Hungary based on the Scopus and Web of Science databases for 2015 - 2024. This study aims to exhibit trends, gaps, and patterns in the water quality topic, illustrating the importance of socio-economic development and environmental sustainability. The results show that in Brazil, environmental monitoring, toxicity and phosphorus analysis are the majority focus on scientific research, and in Hungary, similar to Brazil, is also concerned with environmental monitoring mainly based on local ecosystems (e. g. Lake Balaton and the Danube River) as well as subjects such as risk assessment and nutrients analysis. The highlight in both countries is the necessity of commitment to international cooperation, which is necessary to develop innovative and sustainable approaches to water management.
Keywords: Bibliometrix; environmental assessment; scientific cooperation.

Uma década de produção científica sobre qualidade da água: uma análise bibliométrica das perspectivas regionais no Brasil e na Hungria (2015-2024)

ABSTRACT: Este artigo realiza uma análise bibliométrica da produção científica sobre qualidade da água no Brasil e na Hungria com base nos bancos de dados Scopus e Web of Science do período de 2015 a 2024. O objetivo desse estudo é exibir tendências, lacunas e padrões no tópico de qualidade da água, ilustrando a importância para o desenvolvimento socioeconômico e a sustentabilidade ambiental. Os resultados mostram que, no Brasil, o monitoramento ambiental, análises de toxicidade e de fósforo são o foco principal da pesquisa científica e, na Hungria, similar ao Brasil também se preocupa com a Avaliação ambiental baseando principalmente em ecossistemas locais (por exemplo, o Lago Balaton e o Rio Danúbio), além de temas como avaliação de riscos e análises de nutrientes. O destaque em ambos os países é a necessidade de compromisso com a cooperação internacional necessária para desenvolver abordagens inovadoras e sustentáveis de gerenciamento de água.
Palavras-chave: Bibliometrix; avaliação ambiental; cooperação científica.

1. INTRODUCTION

Water quality is one of the fundamental bases for establishing a balanced environment, with direct implications for socio-economic development and the maintenance of ecosystem services. In recent years, there has been an intensification of studies related to the quality of environments, especially water quality, addressing the effects of the continuous degradation of water resources as a result of global disorderly urbanization, increased by agricultural activities, industrial pollution, among others (CHUNG et al., 2021). Affecting a global scale and intensified by climate change, pollution by heavy metals, nutrients, microplastics and pharmaceutical waste directly influences the availability and quality of water.

In some instances, human practices cause irreversible damage that affects entire river systems. The environmental disaster in the Doce River basin in 2015 shows what happens when anthropogenic activities lead to permanent damage to a river system for the water quality and the unrecoverable costs to the community that relies on this resource (KÜTTER et al., 2023; YAMAMOTO et al., 2023). The failure of the Fundão dam in the Doce basin released approximately 55 to 62 million m^3 of mining tailings. It resulted in a problematic environmental disaster that took years to repair and permanently altered the river system (KÜTTER et al., 2023).

Faced with these challenges, regular assessments of water quality have become an essential management option through which water resources and their quality can be managed sustainably. Countries like those in Eastern Europe, in the Danube River area, have also shown that continuous monitoring programs can expose very complex problems, for example, the introduction of microplastics and excess nutrients, which will require an integrated management approach; the complications develop as the issues do not stop at national boundaries (LECHNER; RAMLER, 2015; STANKOVIĆ et al., 2024).

In the 2030 Agenda for Sustainable Development, the relevance of water quality for creating future public policies was highlighted, ensuring water pollution control as one of

the national and global priorities agenda (BASSEM 2020). Results reported in the study by McDonald et al. (2016) showed that 90% of the watersheds that contribute to the water supply of cities have experienced a decline in water quality since the beginning of the 20th century. This decline is due to increases in nitrogen and phosphorus resulting from anthropogenic activities, such as changes in agricultural land use.

According to the World Water Assessment Programme (WWAP) report (2017), globally, approximately 80% of urban wastewater is discharged without any treatment procedure into water bodies, and industrial activities are responsible for these discharges of millions of tons of pollutants annually (solvents, heavy metals, and toxic sludge).

Technological and methodological advances have occurred in the last 10 years, from 2015 to 2024. Older methodologies, such as water quality indexes (Water Quality Index - IQA or, in English, WQI) and bioindicators, have helped assess and monitor water resources. These studies are extremely important for environmental assessment, as they establish a connection between public policies, science, and greater adaptability to climate change.

Considering the global context, guidelines at the international level, such as the Water Framework Directive (WFD) of the European Union and the National Sanitation Foundation USA (NSF), stand as benchmarks for a particular water environment to achieve and target water bodies (CHIDIAC et al., 2023). At the same time, these policies have struggled through local adaptation. In this sense, Brazil, with its own salient environmental and socio-economic challenges, as some authors pointed out, has globally endless water policy inconsistencies, making scientific research indispensable for public policy formulation (ARAÚJO et al., 2015; FERREIRA et al., 2019; MELLO et al., 2020).

To understand these geographical differences and challenges, a thorough look at scientific production can help provide key trends and knowledge gaps. Trying to understand how water quality research evolves across geographies can identify patterns, techniques and methodologies for updating public policies and adopting the most suitable behaviours for public water consumption.

The selection of Brazil and Hungary for this bibliometric analysis is explicitly founded on their hydrographic, socioeconomic, and institutional differences, which expose paradigmatic challenges in water quality management. Brazil, which has 12% of the fresh surface water on the planet (ANA, 2023), experiences typical developing countries issues regarding watershed deforestation (responsible for 40 % of sedimentation of rivers; Mello et al., 2020) and poor sanitation (with only 55% of its population adequately collected by sewage; SNIS, 2023). By comparison, Hungary, which could indicate that 95% of water resources flow towards the Danube (ICPDR, 2023), indicates the European challenges of historical pollution by heavy metals (Dávid, 2018) and eutrophication with intensive agricultural activities (75% of waters with excess nitrogen; Eurostat, 2023). We can explore a greater duality in understanding the extent to which different geopolitical contexts allow for shifts in the scientific production on water quality.

The contrast becomes even more relevant given their different governance models. Brazil has decentralized basin management (Law No. 9.433/1997). However, it has institutional fragmentation (Pereira et al., 2022), while Hungary is governed with strict targets similar to the EU Water Framework Directive (2000/60/EC) until 2027. Both share climate vulnerabilities; Brazil is experiencing extreme droughts in the Amazon (Castello et al., 2022), while Hungary is experiencing continuous flooding on the Danube (ICPDR, 2023). These differences mean that the scientific output of these countries serves as a thermometer for the usability of global priorities in water research.

During the research process, the trends and gaps found in the scientific production are necessary to evaluate the specific topic proposed. Bibliometric reviews are of great importance for summarizing existing knowledge, identifying trends, assessing the influence and impact of publications, as well as, serving as a basis for new research and projects (WANG et al., 2022). According to Pritchard (1959, p. 39), the term 'bibliometrics' is defined as "[...] the application of mathematical and statistical methods to books and other media".

The bibliometric analysis used the R language with the Bibliometrix package (ARIA; CUCCURULLO, 2017). Bibliometrix provides a rich set of tools for bibliometric analysis, and its web interface component, Biblioshiny, was employed to avoid complex programming. This can be used even if the users are not experienced in programming.

This study aims to perform a bibliometric analysis of scientific literature in the past 10 years (2015 - 2024) to identify research trends and scientific production patterns of water quality (including specific research conducted by Brazilian and Hungarian groups). Through this analysis, we analysed core areas of research to get an overview of how publications are developing over time (academic scenario as a whole) on this topic, to draw attention to parts not considered to produce efficient public policies and sustainable water conservation.

2. MATERIAL AND METHODS

2.1. Data and Methods

For this bibliometric study, Web of Science (Clarivate Analytics) and Scopus (Elsevier) were chosen as primary data sources due to their complementary strengths in covering high-impact scientific literature (MONGEON et al., 2016). Web of Science, with its rigorous journal selection process through the Journal Citation Reports (JCR), remains a gold standard for tracking citation networks and interdisciplinary research trends, particularly in social sciences and fundamental sciences (BIRKLE et al. 2020; ZHU; LIU, 2020). Scopus provides wider coverage, especially in engineering, health sciences, and rapidly growing fields, with approximately 20% more journals than WoS (Baas et al., 2020), which makes Scopus more comprehensive for mapping all the literature.

Using both databases reduces the chance of bias in using only one platform for analysis (HU et al. 2018; ZHU; LIU, 2020). WoS has a depth and long history of its citations (1945-present), while Scopus includes more non-English publications and bibliometric indicators like CiteScore and Field-Weighted Citation Impact (FWCI) (JAMES et al., 2018; ZHU; LIU, 2020). Both databases have been shown to use citations from different published journals, so we must verify our conclusion through scanning both for the same literature piece of research (HU et al. 2018; ZHU; LIU, 2020). A dual-database approach, like we have demonstrated here, provides an opportunity to cross-examine and give more authoritative conclusions on scientific papers following documented best practices for systematic research evaluation, and for example,

the recent work on innovation ecosystem and intellectual capital (ARCHAMBAULT et al., 2009; SINGH et al., 2021).

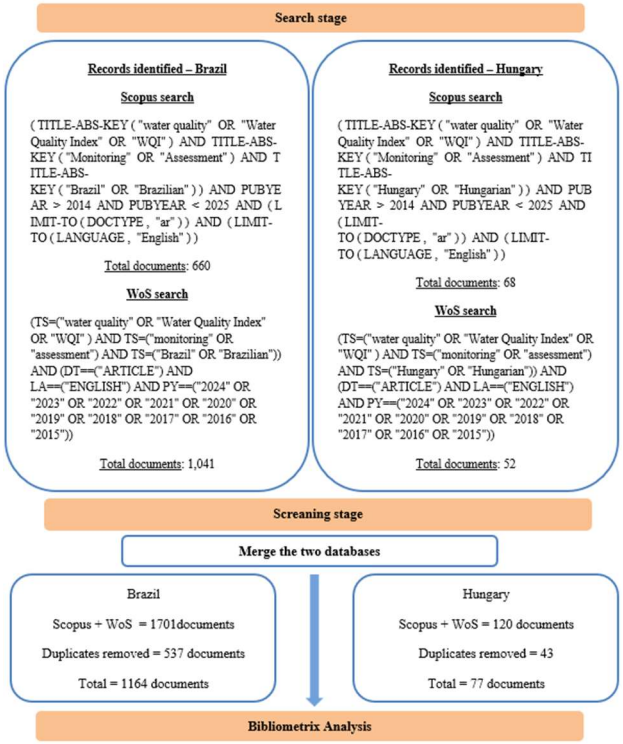

Figure1. Flowchart for a bibliometric analysis study.
Figura 1. Fluxograma do estudo de análise bibliométrica.

The bibliographic search method followed the steps in the study's methodological flowchart (Figure 1). It was searched in the Scopus and WoS databases using TITLE-ABS-KEY and TS (Topic) operators to obtain scientific articles that included the search terms in their title sections and abstracts or keyword fields. The period specified for the research spanned from 2015 to 2024 to reflect scientific works from the previous ten years. English-language full articles served as entry criteria for this study since they enabled international outcome compatibility and unified data analysis between the databases. The research method of strict bibliographic corpus construction provided the foundation for the following bibliometric analysis: Annual Scientific Production, Most Productive Authors, Top Manuscripts per citations, Most Relevant keywords (Author's Keywords), Countries Collaboration World Map, Most Relevant Sources, Most Relevant Affiliations, and Trend Topics.

We executed a meticulous standardization procedure for authors' and institutions' names to maintain data consistency in bibliometrics. The preliminary analysis revealed inconsistencies in the Author (AU) field as different author format elements, including 'De, Da, Das' and compound names, appeared in different styles. The decision to employ authors' complete names (AF – Author Full Name) produced better identification results, so we adopted this method. Ten of the most productive authors received manual inspection with standardized citation ordering procedures. We discovered linguistic adversity (English and Portuguese institutions' names) and variable abbreviation styles for institutions across multiple publications. We standardized institutional names to their official current designations to prevent duplicate counting of equivalent institutions caused by spelling differences. The hand-based standardization process proved necessary to create accurate data for the institution, and the author's productivity analysis is found in the results.

3. RESULTS

3.1 Global

Our selected search terms for 2015 through 2024 yielded 37,355 articles from Scopus and 24,758 articles from the Web of Science (WoS). The search was made on 20th April 2025, looking at articles related to "Water Quality," "Water Quality Index," "WQI," "Monitoring," and "Assessment."

The yearly number of publications shows that both databases exhibited an overall increase across the years, with Scopus showing an overall higher publication rate than WoS (Figure 2).

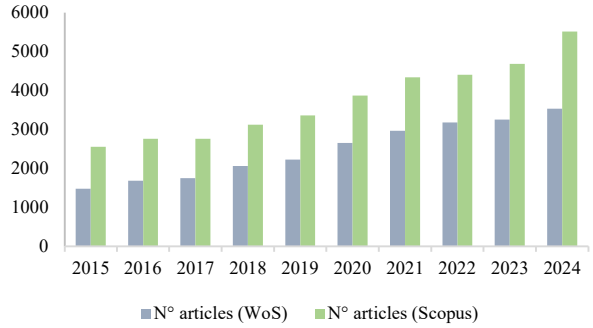

Figure 2. Annual evolution of the number of articles indexed in Scopus and Web of Science (2015-2024).
Figura 2. Evolução anual do número de artigos indexados na Scopus e Web of Science (2015–2024).

Regarding country-level contributions, the top 10 countries have 28,730 articles on Scopus and 19,209 articles in WoS. China was the leading contributor, accounting for 21.7% of Scopus and 21.3% of WoS publications (Table 1). The USA was the second contributor, with 18.5% of Scopus publications and 19.3% of WoS publications. India placed third in both Scopus and WoS, with a share of 9.5% in Scopus compared to 8.7% in WoS. Brazil contributed 3.9% in both Scopus and WoS, which had the same position in terms of scientific output on the topic.

Overall, the trends observed reflect not only the increase in interest worldwide in water quality monitoring and assessment but also potential differences in coverage and indexing policies between the two sources of information. This reinforces the need to cross-reference more than one database in bibliometric analysis.

3.2. Brazil and Hungary

After the global bibliometric analysis, as described in the methodological flowchart, the search terms 'Brazil' OR 'Brazilian' and 'Hungary' OR 'Hungarian' were used to select country-specific publications for the Brazilian and Hungarian cases.

Brazil had 1,164 articles published between 2015 and 2024, while Hungary had 77. Brazilian production was irregular, with peaks in 2021 (153) and 2024 (151), while Hungary was stable with 2-13 articles per year (Figure 1A and 1B). One exception was 2018, when Hungary had two articles; this could be because 1) there was production but not in English, and 2) due to changes in research policy or funding. The absolute difference is due to the size of the two

countries' scientific systems, but normalized analysis reveals subtler patterns.

Table 1. Ranking of the 10 countries with the highest scientific output (number of articles), according to indexing in Scopus and Web of Science (2015-2024). Percentage figures refer to each country's relative contribution to the number of articles per base.
Tabela 1. Ranking dos 10 países com maior produção científica (número de artigos), conforme indexação na Scopus e Web of Science (2015–2024). Valores em porcentagem referem-se à contribuição relativa de cada país no total de artigos por base.

Countries	Scopus	%	Countries	WoS	%
China	8,101	21,7	People R China	4,622	21,9
United States	6,902	18,5	USA	4,196	19,0
India	3,541	9,5	India	1,898	9,2
Canada	1,758	4,7	Canada	1,054	4,8
United Kingdom	1,723	4,6	Australia	1,026	4,6
Australia	1,614	4,3	Germany	897	4,0
Brazil	1,458	3,9	England	866	3,9
Germany	1,404	3,8	Brazil	843	3,9
Spain	1,139	3,0	Spain	689	3,1
Italy	1,090	2,9	Italy	770	3,1
TOTAL	28,730			19,209	

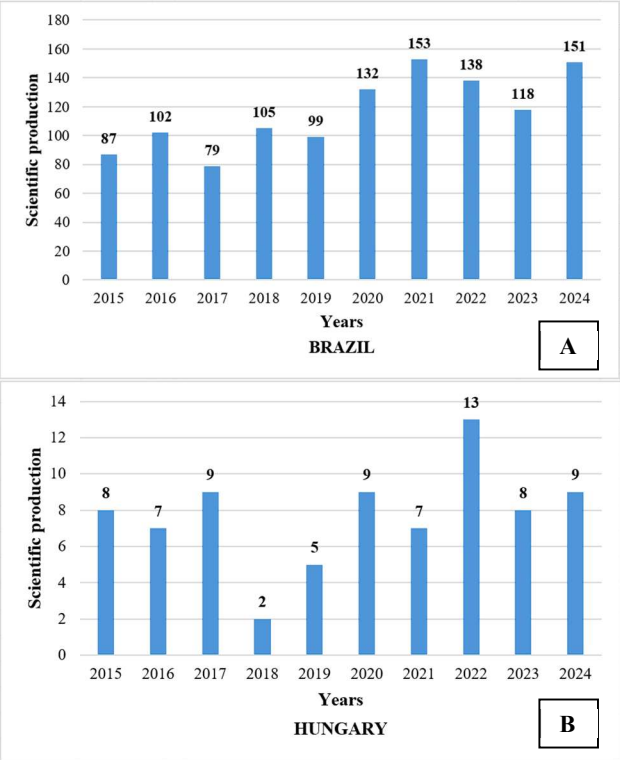

Figure 3. Number of articles published per year (2015-2024): comparison between Brazil (A) and Hungary (B).
Figura 3. Número de artigos publicados por ano (2015-2024): comparação entre o Brasil (A) e a Hungria (B).

When normalized by author, productivity was the same: 0.20 articles per author in Brazil and 0.18 in Hungary. However, Hungary stood out in international collaboration (25.97% of articles with foreign authors, vs 16.32% in Brazil). Additionally, the average number of co-authors per article was slightly higher in Hungary (6.51 vs 6.03), possibly because of the smaller size of scientific groups (Table 2).

The average impact per article, by citations, was the same: 14.41 citations/article in Brazil and 12.83 in Hungary. Nevertheless, Hungary had more thematic diversity, with 4.40 unique keywords per article (vs 2.79 in Brazil), possibly due to more multidisciplinary or exploratory research. Brazil focused on fewer high-impact journals (3.45 articles/source vs 1.43 in Hungary), possibly due to different thematic priorities or publication strategies.

Table 2. Comparison of bibliometric metrics (Brazil vs. Hungary, 2015-2024).
Tabela 2. Comparação de métricas bibliométricas (Brasil vs. Hungria, 2015-2024).

Indicator	Brazil	Hungary
Total articles	1,164	77
Average Articles/Author	0.20	0.18
International Collaboration	16.32%	25.97%
Co-authors per doc	6.03	6.51
Citation/article	14.41	12.83
Keywords/article	2.79	4.40

Regarding international scientific collaboration, Brazil measures higher overall research output, while both countries demonstrate similar output efficiency levels according to their scientific groups. With a smaller scientific community, Hungary compensates through international collaborations and thematic diversification (Figure 4A and B).

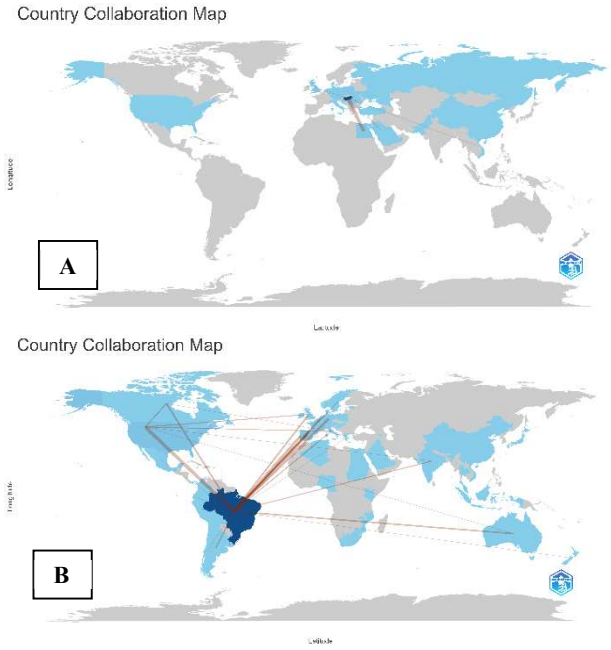

Figure 4. Country collaboration map. Brazil collaboration (A) and Hungary collaboration (B).
Figura 4. Mapa de colaboração entre países. Colaboração do Brasil (A) e colaboração da Hungria (B).

Hungary has shown interaction with Egypt and Saudi Arabia, as other members of the European Union, with countries geographically closer (Poland and Romania). Brazil's extensive international collaboration network in scientific publications. The analysis reveals that the United States is the main partner, with 134 collaborations, followed by Portugal, Germany, Spain and the United Kingdom, respectively. This cooperation network demonstrates a diverse and global integration, not only strengthening Brazilian scientific production but also promoting the exchange of knowledge and innovation, contributing to the advancement of science for the benefit of society.

Among the top 10 institutions with affiliated authors in water quality research (2015-2024) (Table 3), the University of São Paulo (USP) led the Brazilian institutions through 248 contributions alongside São Paulo State University (UNESP) (163) and the Federal University of Paraná (UFPR) (133). The scientific research in Hungary focuses primarily on two institutions that account for 75 mentions and demonstrate strong centralization of their research domain. The dominance of public universities in Brazil (e.g., USP, UFPR) and government-linked networks in Hungary (e.g., Hun-Ren) underscores the role of public funding in driving environmental research.

Article publications demonstrate unique scientific developmental traces between Brazil and Hungary. The relationship between institutional profile and publishing strategy becomes even clearer when we examine the main journals in which researchers in both countries publish. While Brazilian universities concentrate their publications in the same journals that serve global researchers, Hungarian institutions take advantage of publishing niches that reinforce their regional networks - a pattern consistent with their collaborative ties shown in Table 4.

Table 4 shows that Brazilian researchers' publications appear mainly in extensive journals, including Environmental Monitoring and Assessment (117) and Science of the Total Environment (79). The same happens with Hungarian researchers, who spread their contributions across international and regional publications. Protecting water quality is a priority academic topic for both countries since both nations recognize "Environmental Science," "Pollution Research," and "Science of the Total Environment" as their top preferred journals of publication.

Figure 5 demonstrates how the main Brazilian and Hungarian authors in water quality research produced their scientific work differently. Oliveira S.C. stands out as the most prominent author in Brazil, with fourteen publications backed by researchers Guedes H.A.S. and Callisto M., each contributing nine articles respectively. Published articles in Brazil form a steep ridge connecting the first researcher with the last researcher because the main authors have an unbalanced distribution of research outputs. The most productive researchers in Hungary demonstrate a balanced output distribution, Balla D. and Mester T. each publishing six articles. Hungary's reduced number of researchers and the collective research approach might explain the diverse article distribution among its scientists. Many Brazilian authors publish articles in absolute terms; however, Hungary displays more uniform productivity across its active researchers. Various elements probably explain this difference, including the greater number of postgraduate programs in the environmental area in Brazil, differences in the incentive systems for scientific publication between the countries, and the fact that Brazilian researchers engage more fully with international research networks focusing on water resources management.

Table 3. Leading Institutions in Scientific Production in Brazil and Hungary (2015-2024).
Tabela 3. Instituições líderes em produção científica no Brasil e na Hungria (2015-2024).

Affiliation - Brazil	N° of articles	Affiliation – Hungary	N° of articles
University of São Paulo (USP)	248	Hungarian Research Network (HUN-REN)	50
São Paulo State University (UNESP)	163	Eötvös Loránd University	34
The Federal University of Paraná (UFPR)	133	University Of Debrecen	24
University of Minas Gerais (UMG)	124	Hungarian University of Agriculture and Life Sciences	18
Federal University of Rio de Janeiro (UFRJ)	105	University Of Pannonia	15
The Federal University of Santa Maria (UFSM)	94	Institute For Soil Sciences and Agricultural Chemistry	10
Feevale University	93	Hungarian Academy of Sciences	8
Federal University of Pernambuco (UFPE)	81	Budapest University of Technology and Economics	7
State University of Campinas (Unicamp)	63	University Of West Hungary	7
University of Brasilia (UnB)	61	University Of Miskolc	6

Table 4. Main journals by scientific production in water quality (Brazil and Hungary) (2015-2024).
Tabela 4. Principais periódicos por produção científica em qualidade da água (Brasil e Hungria) (2015-2024).

Ranking	Brazil	N° of Articles	Hungary	N° of Articles
1	Environmental Monitoring and Assessment	117	Environmental Science and Pollution Research	6
2	Science of the Total Environment	79	Science of the Total Environment	6
3	Environmental Science and Pollution Research	62	Water	5
4	Marine Pollution Bulletin	35	Carpathian Journal of Earth and Environmental	3
5	Chemosphere	27	Ecological Indicators	3
6	Water	27	Acta Carsologica	2
7	Water, Air, and Soil Pollution	27	Central European Geology	2
8	Brazilian Journal of Biology	24	Ecological Engineering	2
9	Environmental Pollution	21	ISPRS International Journal of Geo-Information	2
10	Revista Ambiente e Água	21	Journal of Water and Health	2

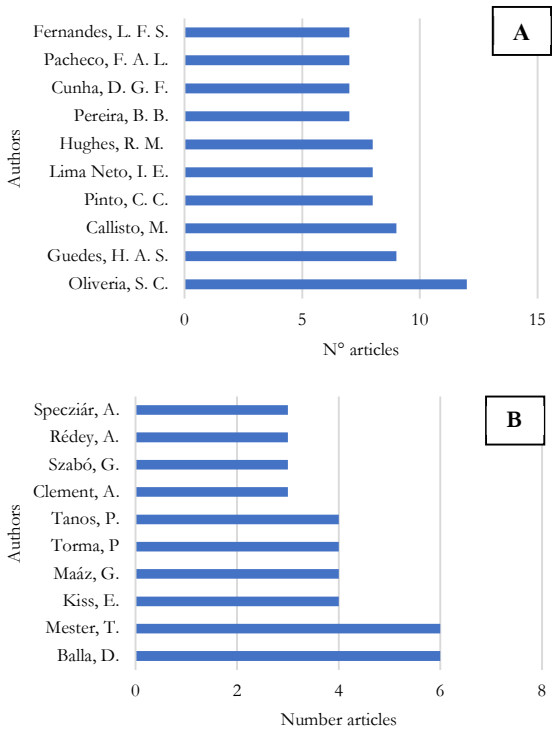

Figure 5. Top 10 most relevant Authors. Brazil (A) and Hungary (B).
Figura 5. Os 10 principais autores mais relevantes. Brasil (A) e Hungria (B).

The scientific analysis of water quality through top-cited articles demonstrates contrasting patterns between Brazil and Hungary regarding their academic influence and research focus (Tables 5 and 6 - attachment). The collapse of Mariana and Brumadinho dams, heavy metals and pharmaceuticals infiltration, and mining contamination of water resources have been the principal research areas in Brazilian environmental studies. Most of these scientific papers appeared between 2015 and 2019 to demonstrate the national research focus on environmental crises through multidisciplinary analytical chemistry, remote sensing, and ecotoxicology approaches.

The Hungarian cited articles primarily examine river measurements of the Tisza and Danube, conduct river filtration assessments, and analyze the presence of pharmaceutical and oestrogen pollution. The time needed to accumulate citations explains why most studies appeared before 2020, since older articles tend to gain greater visibility in academic literature. The country collaborates with European research institutions to conduct numerous studies while strengthening its position in the international scientific network.

Regarding the keywords most used by the authors in their publications (Figure 6), in both countries, the terms "Water Quality" and "Water Quality Index" were expected, given that the search was carried out using the terms that appeared in the Title, Abstract, and Keywords in both databases. In Brazil, terms such as "Eutrophication", "Metals", "Biomonitoring", "Water Pollution", and "Pollution" were not present in the search terms, but they are related to the topic. In Hungary, the terms "Heavy Metals", "Lake Balaton", "Chlorophyll-A", "Cleaning Process", "Eutrophication", and "Karst" were also not mentioned in the search but were found in the keywords.

The term "Karst" mentioned in the keywords refers to a mountainous region in northern Hungary, geological formations called Aggtelek Karst (GERCSÁK, 2002).

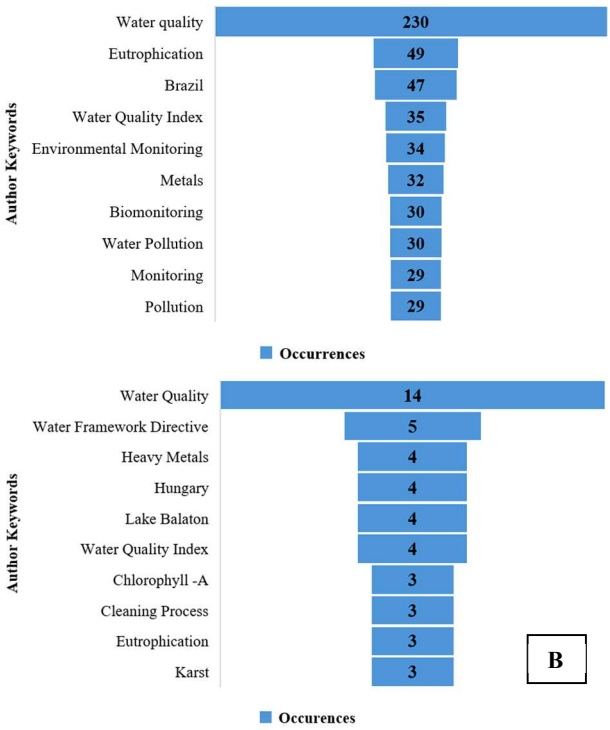

Figure 6. Keywords most used by authors in scientific publications in Brazil (2015-2024). Brazil (A) and Hungary (B).
Figure 6. Palavras-chave mais usadas pelos autores em publicações científicas no Brasil (2015-2024). Brasil (A) e Hungria (B).

The thematic map in the bibliometrix is related to the most frequent keywords in scientific publications. It uses the Keyword Plus for the analysis. The graph is divided into four quadrants: (i) Emerging or Declining themes, (ii) Niche themes, (iii) Motor themes, and (iv) Basic themes. Each point represents a keyword, whose position reflects its centrality (relevance in the field) and density (degree of development of the topic), showing which topics are popular and which need more focus. The Basic themes are fundamental to the field but still need to be explored more, while the Motor themes are well-developed and important for the field. Niche themes are specialized and well-developed but poorly connected to other themes, and emerging or declining themes can be new trends or areas that are losing relevance.

The thematic map in Brazil (Figure 7A) shows relevant topics, demonstrating the Basic themes of Pollution, Lake, Land-use, Quality, and Management. This indicates that these subjects are widely studied in Brazil and highly relevant within the scientific community, but perhaps without much in-depth theoretical development. On the other hand, the Emerging or Declining themes, represented by River-basin, Impacts, Indicators, and Diversity, suggest that the terms are present in the literature, but may be undergoing a transition, either in terms of approach or relevance in the scientific community.

In addition, the Niche themes, such as Climate-change, Risk-assessment, Wastewater and Surface-water, suggest that these themes are well developed (high density) but have low connection to other areas (low centrality). The Motor themes, represented by Water Quality, Environmental Monitoring, Toxicity, and Phosphorus, are those with high centrality and

high density, i.e. they are well developed and essential to the field of study, highlight the growing relevance of environmental monitoring and the studies evaluating the toxicity in the detection of chemical contamination, which are areas with strong development and impact in national research. Some terms are centrality of relevance and density, such as Heavy Metals (between emerging or declining themes and basic themes) and Conservation (between emerging or declining themes and niche themes).

The map (Figure 7B) provides an overview of the research's conceptual structure during the period analyzed in Hungary. Similar to Brazil, Hungary contains terms in centrality of relevance and density, such as Contamination, Classification, and Index (between basic themes and motor themes), and Climate-change and Groundwater (between basic themes and emerging or declining themes), indicating that these terms are used and underpin the structure of research in the area. Motor themes: Environmental Monitoring, Water quality, Nitrogen, Phosphorus, Wetlands, Drinking Water, Risk Assessment, and Water supply, suggesting that there are highly developed and central keywords that directly drive research. In niche themes, terms such as environmental quality, floodplain, and fluvial deposit appear as developed topics but have less connection to the core of the research. On emerging or declining topics, Impacts, Land-use, Indicators, Freshwaters, Multivariate Statistical Techniques, Uranium and Wastewater are represented by a highlighted cluster, suggesting that these topics are relevant, but may be undergoing changes in their centrality in the scientific field.

Both countries share similar terms, but in different positions. These findings highlight the consolidation of essential topics and the need for greater integration between advanced methodologies and studies applied to water quality in both countries.

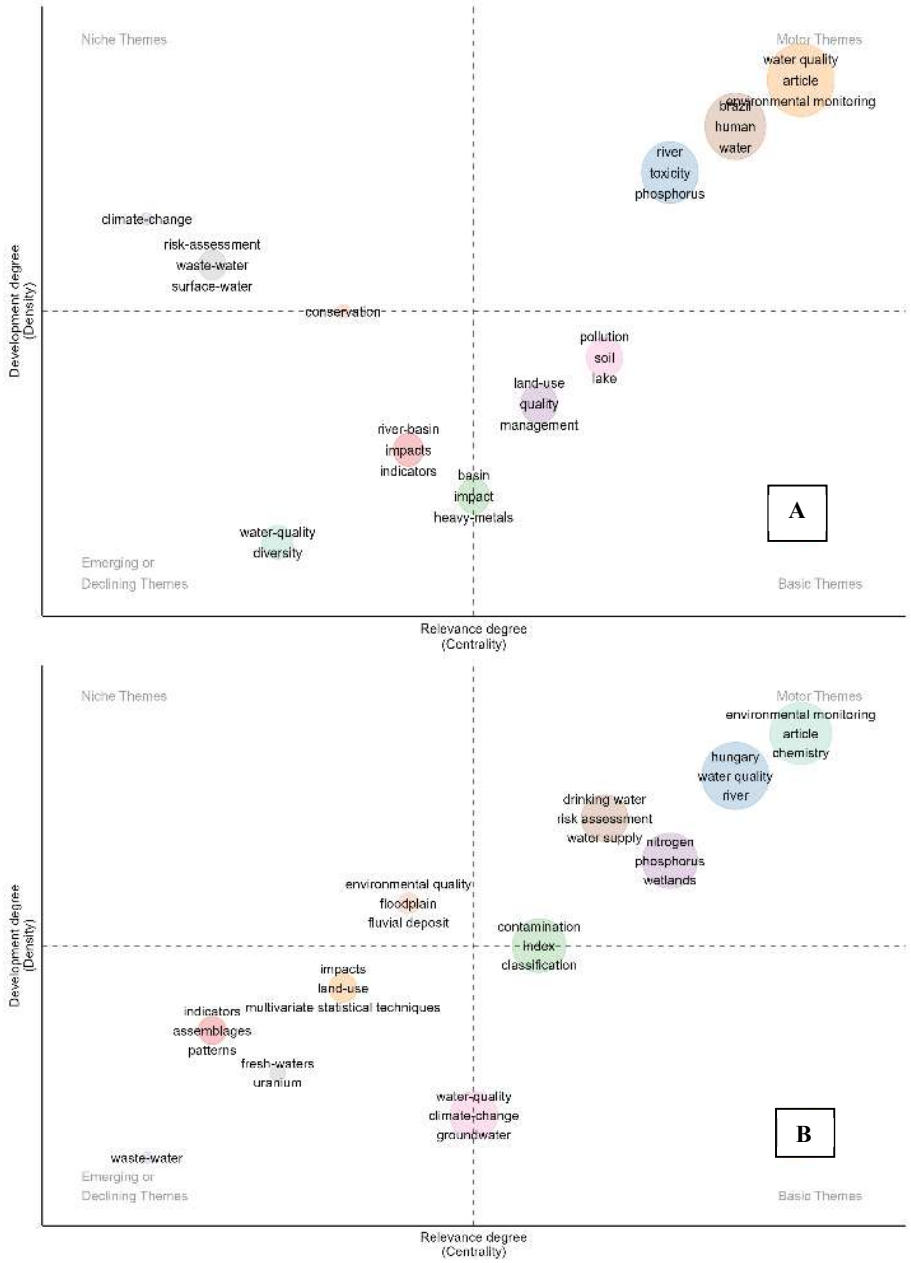

Figure 7. Thematic map of the most frequent keywords in publications in Hungary (2015-2024). Brazil (A) and Hungary (B).
Figure 7. Mapa temático das palavras-chaves mais frequentes em publicações na Hungria (2015-2024). Brasil (A) e Hungria (B).

4. DISCUSSION

Some research in recent years has pointed towards the results of this bibliometric analysis, which reveal significant patterns in scientific production on water quality in Brazil and Hungary over the last decade, offering valuable insights into research trends and existing gaps. The temporal evolution of publications, the geographical distribution of studies, and the main topics covered highlight the growth of academic interest in the subject and the differences and similarities between the two countries. This section discusses the above results from the global water quality research perspective, analyzes their implications for public policies, and suggests actions for future research.

Collaborations between nations initially enabled the transfer of knowledge, methodologies and resources that facilitated more comprehensive, innovative approaches (DUSDAL; POWELL, 2021; HEISER, 2023; DUERKOP et al., 2024). Local researchers and experts from other countries and continents have collaborated substantially for Brazil and Hungary. Besides, research carried out through collaborative projects is often supported by additional funding and infrastructure, which offers the opportunity to generate more rigorous/ impactful studies (MCMANUS et al., 2020).

According to Wang et al. (2015), international collaboration enhances the visibility and impact of research. Articles from international partnerships usually gain a broader audience, and articles read in high-quality journals are more likely to be disseminated to global databases. The international publications that are more cited reveal the importance of relevance and field recognition to scientific work (KHOR; YU, 2016).

International collaboration is especially relevant to water quality, an issue that transcends frontiers and where solutions must be context-sensitive for different regional settings (MARGERUM; ROBINSON, 2015). Collaborative work delivers appropriate results by comparing regions (e.g., Hungary and Brazil) and helps to strengthen regional technology, method and data exchange. This means that collaborative science also aids in the creation of better, more sustainable public policy (MARGUM; ROBINSON, 2015).

Scientific publications analyzed the scope of water quality in Hungary and Brazil up to 2015-2024. They also showed different directions: Fast-growing trends, mainly with high national and international collaborations, lead Hungary; at the other end of the spectrum, stable production reaffirms old traditions in environmental research and water issues in Brazil. These two contexts also point to the need for international collaboration in many areas of common problems, such as water scarcity and pollution, as well as international partnerships that increase the reach of the research and work toward longer-term solutions.

Water quality surely represents one of the most sensitive issues for Brazil and Hungary, and it is a source of lots of scientific research in these fields. While in Brazil, the most important problems are pollution from agriculture, urban infrastructure and mining; deforestation and insufficient sanitation, which affects water quality degradation; and water security (MELLO et al., 2020; GESUALDO et al., 2021). In Hungary, the correlation in management of Danube River, agriculture/industry wastes, and drinking water quality is a challenge (CANTONALI et al., 2020; ZWĘGLIŃSKI; BALATONYI, 2021; SAEIDI et al., 2023).

Both countries' thematic maps and top-cited articles show complementary evidence of the distinctive but related research profiles, influenced by their socio-environmental settings and scientific focus. In the case of Brazil, the articles present a clear concern with acute environmental crisis and contamination of water resources, which is well related to the driving themes identified by the thematic map, such as water quality, environmental monitoring, and toxicity. As mentioned before, other studies, for example, Segura et al. (2016) of the Mariana disaster and Thompson et al. (2020) on Brumadinho, reveal the importance given to acute effects and heavy metals in the Brazilian research, confirming the importance of the "metals-monitoring" axes presented under the thematic analysis. Likewise, studies of new contaminants, such as those by Pereira et al. (2016) and Reis et al. (2019), ratify the relevance of environmental analyses as the main theme of the country's scientific production.

Meanwhile, Hungarian scientific output supports a more selective use of sophisticated technology solutions and proactive water management, for example, in the publications of Palmer et al. (2015) on satellite algorithms and Csábrági et al. (2017). Regarding the thematic analysis findings of great density and centrality driving issues, Hungary's front position in creating and using advanced monitoring methods aligns exactly as shown on neural networks used on water quality. Moreover, studies such as the one by Kondor et al. (2020) focus on the pollution through pharmaceuticals, which was also studied in Maász et al. (2019). Another key point emphasized on the thematic maps is the powerful weight of European legislation in directing local studies regarding riverine filtration in the Danube.

The contrast between the two nations shows clear variations in their scientific methods. Deep theoretical insight and methodological integration are sometimes missing in research Brazil generates with a quick and applied focus. Still, it tackles substantial environmental difficulties, including mining disasters and pervasive pollution. On the other hand, Hungary builds more proactive and technologically advanced studies within the European framework of sustainable resource management, grounded in public policy and sophisticated analytical techniques. This complementarity implies excellent chances for cooperation: Brazil might gain from Hungarian knowledge in modeling and monitoring technologies, and Hungary from Brazil's expertise in tackling major environmental disasters.

This is significant for future study, especially in merging interdisciplinarity approaches with more global networking. Important areas of possible collaboration, as in the case of similar contents underlined in Brazil and Hungary, when highlighting topics, can be the use of new biomonitoring approaches (widely used in Brazil) in some habitats (e.g., Lake Balaton in Hungary). Also, discovering fresh and specific issues in these two nations will help develop future studies that can contribute to both theoretical and practical development on water quality (an essential step when tackling such global issues as pollution, environmental crisis, shortage of water, and climate change).

5. CONCLUSIONS

The findings of this study show that the research priorities and socio-environmental circumstances of Brazil and Hungary were reflected in this bibliometric research by different but complementary scientific outputs on water quality. Whereas Brazil uses practical and immediate methods

to tackle urgent issues such as environmental catastrophes and extensive pollution, Hungary distinguishes itself by its advanced surveillance technology and preventative measures by European standards.

This complementarity allows strategic partnerships, where Hungary may learn from Brazil's experience handling major environmental issues, and Brazil may adopt predictive and creative strategies. The examination also uncovered disparities, including the necessity of more theoretical and cross-disciplinary integration in the Brazilian case and the chance to enlarge research on resilience to extreme events in the Hungarian context.

International cooperation is becoming vital to address worldwide problems, including water scarcity and pollution, that call for connected but localized answers. The sharing of information between the two nations, as the use of Brazilian biomonitoring methods in the Hungarian environment (annually, Lake Balaton) or the modification of sophisticated Hungarian statistical models for forecasting mining effects in Brazil, can produce theoretical and practical advancements. Finally, this research underlines the vital need for public policies founded on strong scientific data and developed via partnerships combining local knowledge and worldwide innovation, guaranteeing more sustainable water management suited to the Anthropocene's crises.

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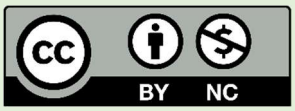
Acknowledgements: I thank the *Stipendium Hungaricum* program for the financial support that made this study possible. I would also like to thank the DRI - Department of Tisza Research at Danube Research Institute in Hungary for the institutional support and infrastructure made available to develop this research.

Authors' contributions: C.E.R.P. – conceptualization, research, methodology, data collection, scientific reading, writing (review and editing), visualization, submission and publication; V.G. advisor, supervision and review. All authors read and agreed to the published version of the manuscriptr

Funding: *Stipendium Hungaricum* scholarship.

Data availability: Study data can be obtained by email from the corresponding author or the second author upon request. It is not available on the website as the research project is still under development.

Conflict of interest: The authors declare no conflict of interest. Supporting entities had no role in the study's design, data collection, analysis, interpretation, manuscript writing, or decision to publish the results.



APPENDIXES

Table 5. Top 10 most cited articles in Brazil.
Tabela 5. Os 10 artigos mais citados no Brasil.

Article Title	Authors	Sources (Journals)	Total Citation	Year
Potential risks of the residue from Samarco's mine dam burst (Bento Rodrigues, Brazil).	Segura, F., Nunes, E., Paniz, F., Paulelli, A., Rodrigues, G., Braga, G., Filho, W., Barbosa, F., Cerchiaro, G., Silva, F., & Batista, B.	Environmental Pollution	202	2016
Occurrence of pharmaceuticals and cocaine in a Brazilian coastal zone	Pereira, C., Maranho, L., Cortez, F., Pusceddu, F., Santos, A., Ribeiro, D., Cesar, A., & Guimarães, L.	The Science of the Total Environment	192	2016
Perfluoroalkyl substances assessment in drinking waters from Brazil, France and Spain	Schwanz, T., Llorca, M., Farré, M., & Barceló, D.	The Science of the Total Environment	152	2016
Estimation of Chlorophyll-a Concentration and the Trophic State of the Barra Bonita Hydroelectric Reservoir Using OLI/Landsat-8 Images	Watanabe, F., Alcântara, E., Rodrigues, T., Imai, N., Barbosa, C., & Rotta, L.	International Journal of Environmental Research and Public Health	151	2015
A 3-year study on occurrence of emerging contaminants in an urban stream of São Paulo State of Southeast Brazil	Campanha, M., Awan, A., Sousa, D., Grosseli, G., Mozeto, A., & Fadini, P.	Environmental Science and Pollution Research	145	2015
The Brazilian Cerrado: assessment of water and soil degradation in catchments under intensive agricultural use	Hunke, P., Mueller, E., Schröder, B., & Zeilhofer, P.	Ecohydrology	144	2015
Severe impacts of the Brumadinho dam failure (Minas Gerais, Brazil) on the water quality of the Paraopeba River	Thompson, F., De Oliveira, B., Cordeiro, M., Masi, B., Rangel, T., Paz, P., Freitas, T., Lopes, G., Silva, B., Cabral, A., Soares, M., Lacerda, D., Vergílio, C., Lopes-Ferreira, M., Lima, C., Thompson, C., & De Rezende, C.	The Science of the Total Environment	138	2020
Dispersal of potentially pathogenic bacteria by plastic debris in Guanabara Bay, RJ, Brazil	Silva, M., Maldonado, G., Castro, R., De Sá Felizardo, J., Cardoso, R., Anjos, R., & Araujo, F.	Marine Pollution Bulletin	124	2019
Time-series analysis of Landsat-MSS/TM/OLI images over Amazonian waters impacted by gold mining activities	Lobo, F., Costa, M., & Novo, E.	Remote Sensing of Environment	122	2015
Occurrence, removal and seasonal variation of pharmaceuticals in Brazilian drinking water treatment plants	Reis, E., Foureaux, A., Rodrigues, J., Moreira, V., Lebron, Y., Santos, L., Amaral, M., & Lange, L.	Environmental Pollution	121	2019

Table 6. Top 10 most cited articles in Hungary.
Tabela 6. Os 10 artigos mais citados no Hungary.

Article	Authors	Sources (Journals)	Total Citation	Year
Validation of Envisat MERIS algorithms for chlorophyll retrieval in a large, turbid and optically complex shallow lake	Palmer, S., Hunter, P., Lankester, T., Hubbard, S., Spyrakos, E., Tyler, A., Présing, M., Horváth, H., Lamb, A., Balzter, H., & Tóth, V.	Remote Sensing of Environment	91	2015
Application of artificial neural networks to the forecasting of dissolved oxygen content in the Hungarian section of the river Danube	Csábrági, A., Molnár, S., Tanos, P., & Kovács, J.	Ecological Engineering	86	2017
Occurrence of pharmaceuticals in the Danube and drinking water wells: Efficiency of riverbank filtration	Kondor, A., Jakab, G., Vancsik, A., Filep, T., Szeberényi, J., Szabó, L., Maász, G., Ferincz, Á., Dobosy, P., & Szalai, Z.	Environmental Pollution	64	2020
Valuation and transferability of the non-market benefits of river restoration in the Danube River basin using a choice experiment	Brouwer, R., Bliem, M., Getzner, M., Kerekes, S., Milton, S., Palarie, T., Szerényi, Z., Vădineanu, A., & Wagtendonk, A.	Ecological Engineering	61	2016
Spatiotemporal variations of pharmacologically active compounds in surface waters of a summer holiday destination	Maász, G., Mayer, M., Zrinyi, Z., Molnár, É., Kuzma, M., Fodor, I., Pirger, Z., & Takács, P.	The Science of the Total Environment	46	2019
β-Estradiol and ethinyl-estradiol contamination in the rivers of the Carpathian Basin	Avar, P., Zrinyi, Z., Maász, G., Takátsy, A., Lovas, S., G.-Tóth, L., & Pirger, Z.	Environmental Science and Pollution Research	38	2016
Prevalence of Legionella in premise plumbing in Hungary	Barna, Z., Kádár, M., Kálmán, E., Szax, A., & Vargha, M.	Water Research	31	2016
Optimization of the monitoring network on the River Tisza (Central Europe, Hungary) using combined cluster and discriminant analysis, taking seasonality into account	Tanos, P., Kovács, J., Kovács, S., Anda, A., & Hatvani, I.	Environmental Monitoring and Assessment	30	2015
Assessing element distribution and speciation in a stream at abandoned Pb-Zn mining site by combining classical, in-situ DGT and modelling approaches	Omanović, D., Pizeta, I., Vukosav, P., Kovács, E., Frančišković-Bilinski, S., & Tamás, J.	The Science of the Total Environment	30	2015
Biodiversity on the waves of history: Conservation in a changing social and institutional environment in Hungary, a post-Soviet EU member state	Mihók, B., Biró, M., Mólnar, Z., Kovacs, E., Bölöni, J., Erős, T., Standovár, T., Török, P., Csorba, G., Margóczi, K., & Báldi, A.	Biological Conservation	28	2017