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A BIBLIOMETRIC ANALYSIS OF RIVER RESTORATION

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Abstract. Increasing environmental pollution and human intervention in nature today require the restoration, study, and monitoring of the positive effects on water quality in the restored rivers. Consequently, the main research questions arise: what are the main trends in river restoration impacting water quality and the watershed ecosystem? How does it contribute to the sustainable development of the environment? To answer these questions, this paper presents the results of the bibliometric analysis of papers from the Web of Science database and a keyword map of water quality in the restored rivers. The results of this study will help scientists and practitioners to monitor the restoration of the river ecosystem and its impact on water quality, and to choose further directions of river exploitation activity.

Keywords: bibliometric analysis, water quality, river restoration, map of water quality.

Introduction

Humans use rivers for irrigation and drainage in agriculture, transportation, drinking water, electricity production by hydropower dams, recreational activities, etc. However, many activities such as channelization, culverting, damming, abstraction, urbanization, pollution, dredging, and intensive agriculture have a negative impact on the river and its environment (Wolf et al., 2021).

A prevailing excess of moisture characterizes Lithuania and certain European territories; therefore, drainage systems were installed to remove excess water from cultivated lands a long time ago. Some lands in Asia, Africa, America, and southern Europe must be irrigated for any agricultural production. Irrigation and drainage are vital to the well-being of people around the world and play an important role in the local, national, and international economics (van Schilfgaarde, 1994).

Due to these human economic activities, the riverbed has been widely transformed, natural river beds were straightened and deepened to artificially form slopes or dammed. These works have changed not only the morphological parameters of rivers but also the flow of water, that makes erosion process more intensive or passive, and the vegetation that grows on the slope of the bed has been removed or changed (Baublys et al., 2017). Such intensive use of rivers for human needs over the past hundred years has changed the natural water flows, their physical and chemical properties, the morphology of the riverbeds, and the species composition of the local flora and fauna (Gregory, 2006; Hajdukiewicz et al., 2019). Human-made dams have effects on fish populations, such as loss of spawning and breeding habitat, deterioration of their quality, or damage to fish in turbines (Song & Mo, 2021).

Intensive human activities have significantly changed the natural hydrological conditions and matter cycling, which are the leading cause of water quality deterioration in the world's rivers (Sibanda & Okoh, 2013). For several decades, the revision of monitoring technologies for stream control has become a hot topic around the world. New methods have been adopted to harmonize agricultural productivity or at least partially restore the lost ecological balance. In many countries, good practice for river restoration has already existed, and in Europe and other continents, restoration projects have been very popular for decades (Bernhardt & Palmer, 2007; Szalkiewicz et al., 2018).

Therefore, in many economically developed countries, mechanical naturalization has been carried out by creating meanders and backwaters in previously straightened rivers and planting trees and bushes along the banks (Dai et al., 2022; Giergiczny et al., 2022; Strobl et al., 2015). In recent decades, a lot of

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efforts have been made to reduce the negative effects of dams and restore damaged fish populations by installing fishways and removing dams (Carlson et al., 2018; Magdaleno et al., 2018).

Consequently, the main research questions arise: what are the main trends in river restoration impacting water quality and the watershed ecosystem? How does it contribute to the sustainable development of the environment? To answer these questions, this paper presents the results of the bibliometric analysis of papers from the Web of Science database and the developed keyword map of river restoration impacting water quality and the watershed ecosystem. The results of this study will help scientists and practitioners to familiarize with the restoration of the river ecosystem and its impact on water quality, and to choose further directions of river exploitation activity.

The structure of the paper is as follows. Section 1 describes the methodology of a bibliometric analysis of river restoration impacting water quality and the watershed ecosystem. Section 2 presents the results of the bibliometric analysis. Section 3 discusses the results and concludes the paper.

1. Methodology

A bibliometric analysis encapsulating the application of quantitative analysis of keywords and their links on bibliometric data on river restoration and water quality topic according to the chronological perspective is presented in this paper. It is conducted as proposed in (Donthu et al., 2021) applying co-words analysis and presented in Figure 1, which is developed employing the PRISMA schema from (Page et al., 2021).

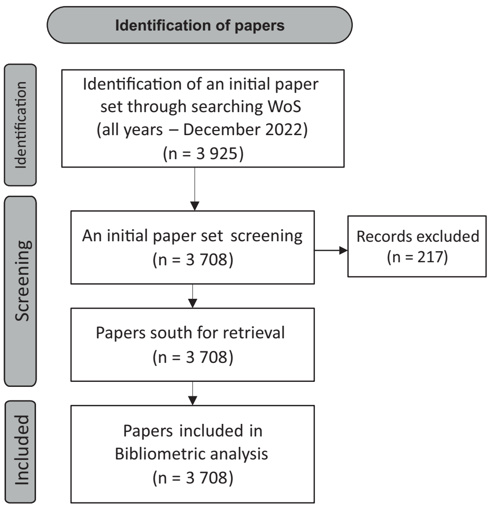

Figure 1. The schema of a bibliometric analysis on river restoration and water quality

This bibliometric analysis aims to explore the topic of river restoration and water quality and its contribution to the sustainable development of the environment. Based on this aim, the research questions are defined as follows:

– What is chronological distribution of papers on river restoration and water quality? (Q1)
– What are the main trends in river restoration impacting water quality and the watershed ecosystem? (Q2)
– How does river restoration impacting water quality contribute to the sustainable development of the environment? (Q3)
– In which countries are the river restoration and water quality being considered? (Q4)

1.1. Searching

This analysis is target on river restoration and water quality without particular limitations. Therefore, the search is defined based on PICOC (Population, Intervention, Comparison, Outcomes, Context) (Kitchenham & Charters, 2007) as follows: 1) population is research papers on river restoration and water quality; 2) intervention – only a partial analysis of river restoration and water quality exists; 3) comparison is not applicable in this paper; 4) the authors of this research do not focus on the outcomes of the analysed papers; 5) academic context, scientific papers on river restoration and water quality.

The search string is developed based on the selected keyword and processed on the Web of Science (WoS) database of scientific publications. Table 1 presents the limitations applied for the search. The categories were target on the chosen research topic of river restoration and water quality and excluded not relevant as Art, Veterinary Sciences, Oncology, Nursing and others. After excluding not relevant categories, the number of papers left suitable for the bibliometric analysis.

Table 1. Searching limitations and results in WoS

Database	Search string	Document Type	Language	Search Results
WoS	"river*" AND "restor*" AND "water*" AND "qualit*"	article OR proceeding paper OR review article	English	3708

This study was conducted in December 2022 without year restrictions on the search. The document type has been limited to articles, proceeding papers and reviews. WoS was chosen for this analysis based on the experience published in and recommendation to choose one suitable database for the bibliometric analysis (Donthu et al., 2021).

The obtained set of paper after the screening was not reviewed additionally according to the inclusion/exclusion criteria (Figure 1), since this paper is target on the global view of river restoration and water quality. Consequently, all papers were transferred for the bibliometric analysis.

1.2. Extracting data and developing a keyword map on river restoration and water quality

A data extraction and a keyword map development were performed automatically applying a bibliographic data mapping and visualization tool VOSviewer (https://www.vosviewer.com/). A co-occurrence analysis of keywords was performed to identify notable keywords from the set of papers and to answer the research questions (RQ2, RQ3). In order to mitigate downsides of co-word analysis (Donthu et al., 2021) and to perform keywords cleaning, the authors of this paper developed the thesaurus according to the rules described in (Kalibatiene & Miliauskaite, 2021). It consists of 101 items for keywords merging or exclusion. Finally, VOSviewer identified 13 886, 289 of which are found at least 15 times in the selected 3 708 papers.

2. Main results

The period (1990–2022, December) of the found papers on river restoration and water quality (Q1) is presented in Figure 2. It shows the increase of the papers (see the dotted trendline in Figure 2) that can be perceived as an increase in the relevance and interest of the analysed topic. In addition, in the last 5 years ~42% of the papers of the entire considered period have been published.

Figure 3 presents the developed by VOSviewer keyword map on river restoration and water quality topic (Q2, Q3) according to Average Publication Year (APY) perspective.

In this map, we can see bubble size, colouring and link perspectives. Bubble size presents the occurrence of a keyword in the analysed papers. The occurrence of all found 289 keywords ranges in the interval [15; 426], which can be divided into three subsets as follows:

- [15; 50] – in this range falls ~71% of all 289 keywords. The biggest occurrence has keywords as follows: reservoir (50), science (49), shallow lake (49), retention (48), runoff (48), environmental flows (45), nonpoint source pollution (45), salinity (45), urban stream (45), hydromorphology (44), organic-matter (44), etc.
- (50; 100] – this range covers ~15% of all 289 keywords with the biggest occurrence as follows: bay (100), phytoplankton (91), connectivity (90), floodplain (89), estuary (88), groundwater (88), growth (88), heavy metals (87), removal (87), biotic integrity (84), scale (82), water framework directive (80), etc.
- (100; 150] – here falls ~5% of keywords, which are as follows: lake (147), catchment (132), patterns (131), fresh-water (130), assemblages (129), river-basin (125), ecology (119), urbanization (118), indicator (115), basin (114), landscape (109), denitrification (107), ecological restoration (106), and flow (103).
- (150; 426] – in this range falls ~9% of all 289 keywords. The biggest occurrence has keywords as follows: management (426), stream (403), land use (400), quality (384), river restoration (319), fish assemblage (307), sediment (274), water (271), phosphorus (260), biodiversity (258), nitrogen (257), macroinvertebrate (239), eutrophication (231), habitat (223), ecosystem (211), climate change (210), community (208), wetland (207), conservation (201), pollution (181), ecosystem services (179), dynamics (163), vegetation (158), diversity (151), and stream restoration (151).

The keywords in the map (Figure 3) are coloured according to APY, showing the average publication year of the papers, in which a particular keyword occurs. All APY rang in the interval (2009; 2020). The newest keywords are presented in yellow colour, the oldest – blue. Consequently, the newest keywords, which APY is higher than 2018, are as follows: surface sediments, blooms, risk-assessment, water quality index, green infrastructure, governance, vulnerability, suitability, multivariate statistical techniques, reduction, trade-offs, identification, threats, and ecosystem services. The amount of those keywords with APY>2018 make up ~5% of all

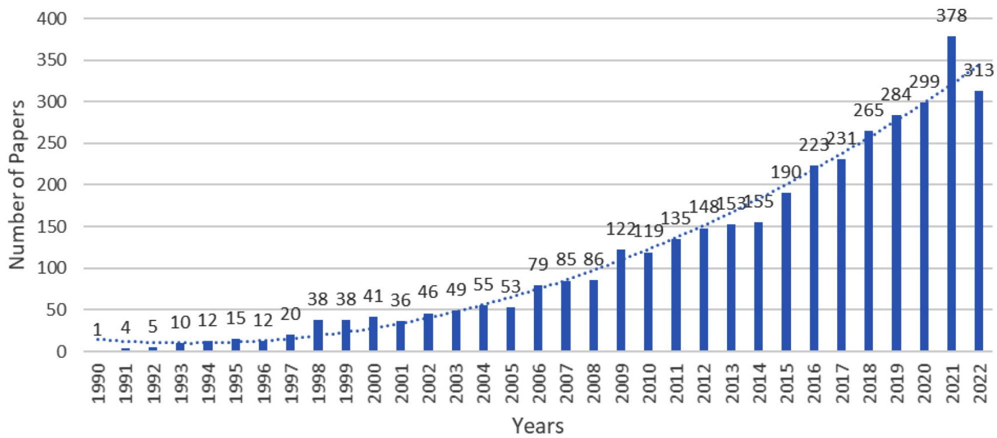

Figure 2. The chronological distribution of papers on river restoration and water quality (Q1)

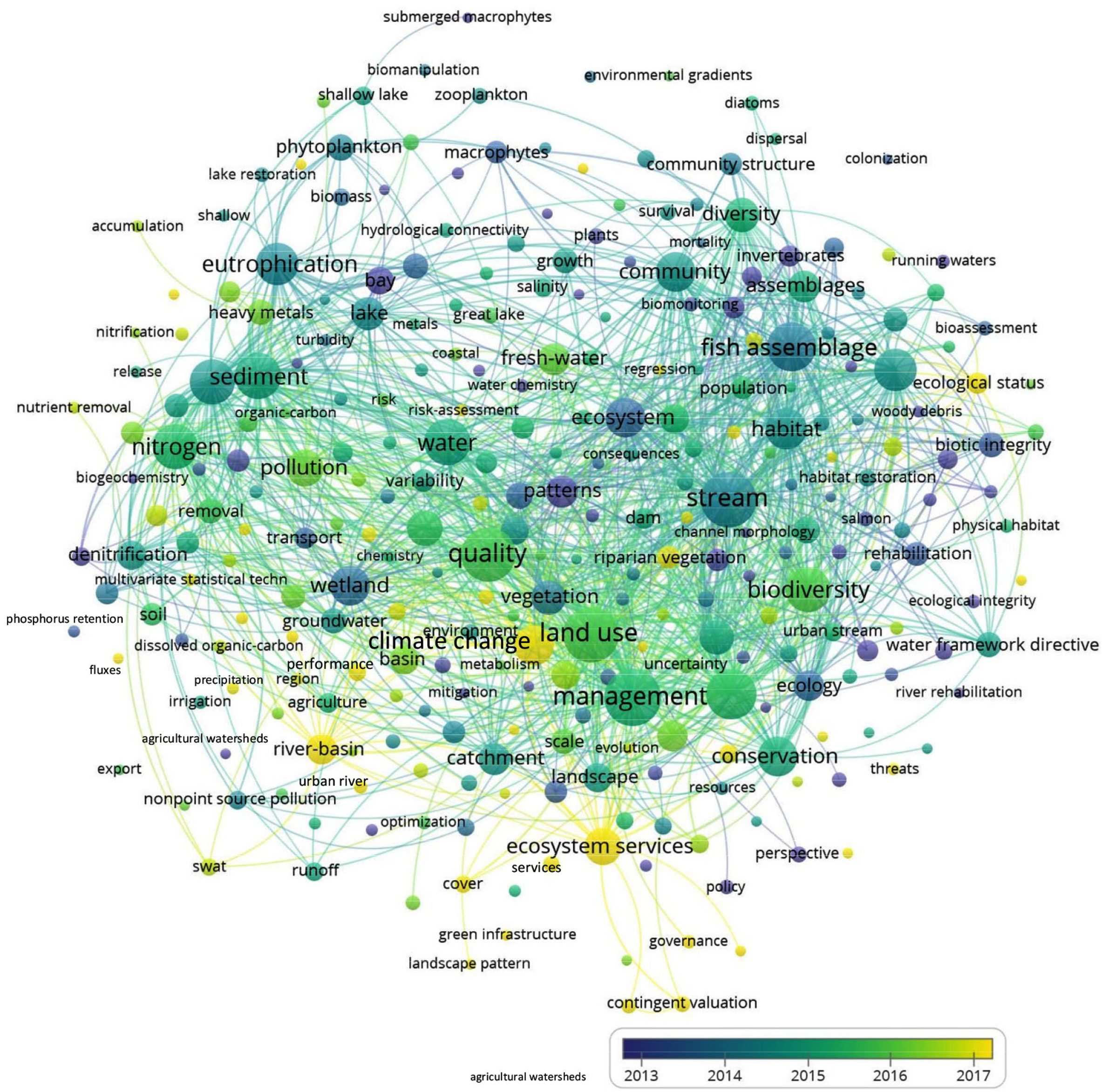

Figure 3. The keyword map on river restoration and water quality (Q2, Q3)

analysed keywords. The following distribution of keywords according to their APY is found:

- [2009; 2010] – covers one keyword or ~0.35%. It is ecological integrity.
- (2010; 2015] – this APY range covers ~51% of all 289 keywords, like hydrodynamics, fisheries, sediment, runoff, release, stream restoration, protection, variability, hydrological connectivity, fragmentation, invasive species, nutrient, irrigation, shallow lake, riparian restoration, landscape, strategies, regime, consequences, water framework directive, habitat quality, growth, riparian buffer, etc.
- (2015; 2020] – here falls ~49% of keywords, some of which are presented above.

However, when analysing the APY perspective of the bubbles, their size or occurrence should be taken into account as well. The relationship of keyword occurrence and colour shows the real life of the keyword in the analysed papers. So, the big bubbles of green colour indicate continuous occurrence of keywords, like land use, biodiversity, quality, etc.

The newest keywords are often small bubbled and yellow coloured, like surface sediments, blooms, risk-assessment, water quality index, green infrastructure, governance, vulnerability, suitability, etc. They are new in the context of the published papers. The oldest keywords are small or moderate bubbled and blue coloured, like agricultural watersheds, ecosystem management, gradient, integrity, sedimentation, acidification, perspective, ecological integrity, etc. Their occurrence in the newest papers is rare.

The biggest links between keywords are found as follows: phosphorus – nitrogen (108), land use – stream (82), macroinvertebrate – stream (75), fish assemblage – stream (65), and eutrophication – phosphorus (64). They

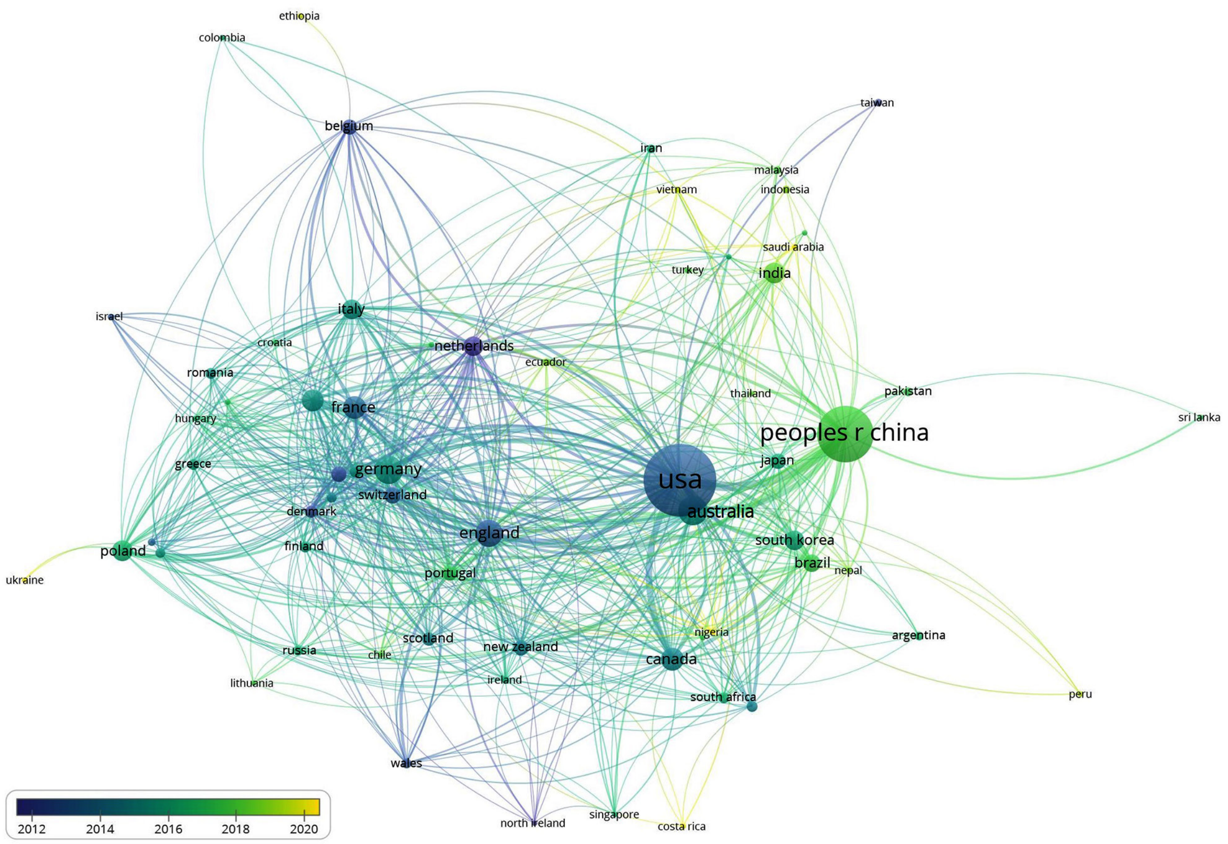

Figure 4. The co-occurrence map of countries publishing papers on river restoration and water quality (Q4)

show the high relationship between keywords, and can form particular topics.

Figure 4 presents the co-occurrence map of countries publishing papers on river restoration and water quality (Q4) according to the APY perspective. The most publishing countries, which number of published papers exceeds 100, are presented in Table 2. It shows that the number of published papers on river restoration and water quality (Q4) in those countries has strong positive correlation (0.66) with the total area of those countries.

The biggest links between countries are found as follows: Peoples R China – USA (87), USA – Canada (51), and USA – Australia (38). Those links show the high cooperation between the found countries.

Table 2. The most publishing countries on river restoration and water quality (Q4)

Country	No. of published papers	APY	Total Area (km^2)
USA	1331	2013.27	9 834 000
Peoples R China	797	2017.61	9 597 000
Australia	213	2015.2	7 688 000
Germany	209	2015.42	357 588
England	190	2013.26	130 279
France	137	2013.70	551 695
Canada	133	2014.79	9 985 000
Spain	120	2015.28	505 990
Poland	108	2016.44	322 575
India	107	2018.00	3 287 000
Italy	103	2015.32	301 230
Netherlands	102	2011.76	41 543
South Korea	100	2015.94	100 210

3. Discussion and conclusions

As the water quality and biodiversity have dramatically in the rivers declined, many ecological restoration projects have been initiated. Water quality has been improved through a combination of river restoration measures such as river bed widening, improving river bank stability with vegetation, creating wetlands and improving flow variability by creating pools and removing dams (Chittoor Viswanathan & Schirmer, 2015). Recently there is already been talk that river water quality and habitats are degraded by thermal pollution from urban areas caused by warm surface runoff, and lack of riparian forests (Abdi et al., 2020). This pollution must also be removed or reduced during river restoration. All these projects aim to improve water quality and restore the ecological continuity of the rivers. Nevertheless, scientists need research and analysis to confirm that restoration projects are effective in improving water quality. The fact that restoration projects improve water quality is not very simple to prove. Chittoor Viswanathan et al. (2015) recommended that in future projects, long rivers be restored and a complete preliminary assessment of water quality based on a predefined quality parameter be carried out prior to some improvements in the rivers. Duan et al. (2022) used a regression discontinuity model to confirm that the restoration projects were effective in improving water quality. Their results showed that water quality tend to improve over time. Chen et al. (2021) wrote that an overall improvement in water quality is observed in only one of the two reclaimed sites, and the measured water quality parameters fluctuate significantly over time. Shahady and Cleary (2021) claim that a belief in water improvements from dam removal can only be supported theoretically whereas a simple dam removal will be ecologically damaging. Consequently, concluding this short review, it shows that the issues of river restoration are relevant and not fully explored yet.

Therefore, this paper presents the bibliometric analysis to answer the questions: what are the main trends in river restoration impacting water quality and the watershed ecosystem? How does it contribute to the sustainable development of the environment?

The chronological analysis of river restoration and water quality and its contribution to the sustainable development of the environment shows a (polynomial) increase of papers Q1 (What is chronological distribution of papers on river restoration and water quality?). This can be associated with the constant interest in the water quality, the growth of its well-being and the sustainable development of the environment.

In order to answer to the Q2 (What are the main trends in river restoration impacting water quality and the watershed ecosystem?) and Q3 (How does river restoration impacting water quality contribute to the sustainable development of the environment?), VOSviewer was used to develop a keyword map of river restoration impacting water quality and the watershed ecosystem based on the papers extracted from Web of Science. It shows that the newly occurring keywords in the scope of river restoration are: surface sediments, risk-assessment, water quality index, green infrastructure, governance, vulnerability, suitability. The most occurring keywords are as follows: biodiversity, quality, nitrogen, management, habitat, eutrophication, ecosystem, ecosystem services, river basin, climate change, pollution. We can also notice pairs of repeated words: conservation – biodiversity; habitat – fish assemblage; land use – catchment, fish assemblage; nitrogen – eutrophication; phosphorus – eutrophication, land use, nitrogen; quality – fish assemblage, land use, management; river restoration – biodiversity, macroinvertebrate, management; sediment – nitrogen, phosphorus; urbanization – land use. This shows that long-standing problems, such as the enrichment of river water with nitrates and phosphates, eutrophication, and the loss of biodiversity, are still relevant. At the same time, new topics related to sustainable environmental protection are emerging, which were previously less studied. Moreover, rivers by themselves are not viewed as a separate component of the environment, but as one of the elements of a sustainable environment. It is one of the green infrastructure corridors contributing to sustainable environmental management.

The analysis Q4 (In which countries are the river restoration and water quality being considered?) of countries investigating shows that the most active and influencing five countries are as follows: United States, China, Australia, Germany and England. Countries that have not considered river restoration and water quality for a long time, but have shown interest in the last five years are Nigeria, Saudi Arabia, Vietnam.

Summing up, rivers are the one of the green infrastructure corridors, which effectively used in human's daily life and affecting his/her well-being. Therefore, they should be maintained and managed according to the sustainable environmental development principles. Consequently, the topic of river restoration and its impact on water quality should be continuously studied.

In the future, we plan to expand this research by analyzing the impact of river restoration not only on water quality, but also on the entire river ecosystem.

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Authors' contribution

Oksana Survilė: Methodology, Related work analysis, Investigation, Visualization.
Diana Kalibatienė: Conceptualization, Methodology, Writing – Original Draft, Visualization, Supervision, Data Curation.

Disclosure statement

In this article, the authors have not any competing financial, professional, or personal interests from other parties.

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