Eutrophication control: the shift to invasive methods managing the internal nutrient loads. A bibliometric analysis

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ABSTRACT

Nowadays severe causes of environmental depletion among water sources are related to excessive disposal of phosphorus and nitrogen nutrients at aqueous environments and subsequently the dominant phenomenon of eutrophication reported via visible cyanobacterial or algal blooms, surface scums, floating plant materials, and benthic macrophyte aggregations. Such environmental pollution problems are also deteriorating by fish kills in aqueous environments, being primarily caused by oxygen shortage and the release of toxic substances. In this research context remediation techniques are directed to control surface runoff to lakes while simultaneously widening riparian buffer zones and constructing wetlands on the main inflow. In this context our study has been developed to gain a deeper insight into eutrophication-related control methods through deploying combined bibliometrics of eutrophication control. These bibliometric analyses have been considered as a credible tool to predict and assess the research history of multidisciplinary scientific topics of local and global academia interest and socio-economic impact. In this respect the bibliometric analysis of our study explored the disciplines of eutrophication control research and lake restoration methods, while identifying the current trends that should abide to environmental remediation. Moreover, our study has jointly identified a wide spectrum of key-aspects of polluted water sources, including internal nutrient loads, water quality, lake restoration methods, sediment capping materials, P inactivation agents and phosphate removal. It was concluded that sediment capping materials, dredging, hypolimnetic aeration, they can jointly approach the theoretical coverage of eutrophication control at related web-search publications, while it can be denoted that no previous bibliometric analyses to date performed keywords-based bibliometric analysis in terms of internal nutrient loads regarding lake restoration.

Keywords: Lake restoration; Eutrophication control; Internal loads; Bibliometric analysis

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1. Introduction

Eutrophication is defined as "a process of pollution that occurs when a lake or stream becomes over-rich in plant nutrient; as a consequence, it becomes overgrown in algae and other aquatic plants. The plants die and decompose. In decomposing the plants rob the water of oxygen and the lake, river or stream becomes lifeless. Nitrate fertilizers which drain from the fields, nutrients from animal wastes and human sewage are the primary causes of eutrophication" [1]. Cultural eutrophication or anthropogenic eutrophication is the process of accumulation of excess nutrients in water ecosystems as a result of human activities that primarily increase the concentration of phosphorus and nitrogen in the ecosystem [2,3]. The mostly affecting human activities are that of overfertilization, industrial and agricultural expansion as well as the release of sewage into water. In such a way cultural eutrophication is the process that speeds up natural eutrophication, especially in both fresh water and saltwater bodies, among which shallow waters are the most susceptible [3]. The excessive disposal of phosphorus and nitrogen nutrients at aqueous environments is the dominant cause of eutrophication detected via visible cyanobacterial or algal blooms, surface scums, floating plant mats, and benthic macrophyte aggregations [4,5]. Subsequently, phosphorus concentration at levels >0.1 mg L^{-1} can generate cyanobacterial (algal) bloom while the release of bounded phosphorus from sediment can be attributed to decayed organic matter. Environmental pollution problems are also worsen by oxygen depletion in aqueous environments, leading to fish kills and the release of toxic substances [4–8].

Among the most traditional techniques of lakes restoration are focusing on reducing nutrients inputs from the catchment, mainly reported through sewage discharge and diffused runoff from agricultural land [9]. These remediation techniques are prone to control stock access to lakes and simultaneously widening riparian buffer zones and constructing wetlands on the main inflow [10]. Besides, such a catchment treatment is capable to maintain eutrophic conditions of high in-lakes concentration, making gradually slower waterbodies recovery caused by high nutrient loads. While the main limiting factor of lake eutrophication is phosphorous, it has been reported that the low mitigation from the sediment to the lake water prerequisites the improvement of water quality at long term periods after the elementary loading incidence [11,12]. In the relevant literature, the main techniques of nutrient fluxes reduction included dredging [13–18], precipitation of phosphorus by aluminum salts [14], in-situ chemical injection [19], hypolimnetic oxygenation [20], as well as in-situ capping [21–23]. Among these techniques it was denoted that the P-inactivation agents can achieve reduction at the rate of sediment nutrient release, followed by inhibition of N and P releases from the sediments under permanent blocking techniques [24,25]. Another important technique is that of in-situ capping, in which a layer is formed at the sediment-water interface, functioning as a sediment-aquatic environment barrier [26]. In such a way the stabilization of sediments can be accomplished without occurring re-suspension but retarding the migration phenomenon of dissolved contaminants into overlying waters [27–29].

Bibliometric analyses have been recognized as credible tool to prediction and assessment the research history of multidisciplinary scientific topics of local and global academia interest and socio-economic impact [23]. Such bibliometric analyses can also elucidate the history background of relevant scientific fields, highlighting research areas of limiting innovation prospects. For the scope of our study it is noteworthy mentioning the study of Zhang et al. [30] who proposed future research perspectives regarding the eutrophication and the climate change interactions occurred in Lake Taihu, while reviewing 1,582 papers related to Lake Taihu published on a timeline of three consequent decades. Similarly, Peng et al. [31] introduced those topics related to ecohydrology and their concurring transformations from a microcosmic to macroscopic level, considering 21,753 papers published at the long-term period 1900–2017. Moreover, various bibliometric analyses have also been focused on aquatic plants [32,33], whereas bibliometric studies on lake restoration interest they have not yet been reported, despite a vivid research interest in the relevant field during the few recent years. In this context, the research objective of our study was to gain a deeper insight into eutrophication-related control methods through deploying combined bibliometrics of eutrophication control. Besides, at our study the conducted bibliometric analysis explored the disciplines of eutrophication control research and lake restoration methods, while identifying the current trends in the abiding fields of remediation. The novelty of our study resides to the fact of a joint identification of a wide spectrum of key-aspects of polluted water sources, including internal nutrient loads, water quality, lake restoration methods, sediment capping materials, P inactivation agents and phosphate removal, being also occasionally or interchangeably reported in the literature. The novel features of our analysis are attributed to the fact that there are sparsely published bibliometric analyses to date used in terms of internal nutrient loads regarding lake restoration. Similarly, there are few bibliometric analyses devoted to the terms of sediment capping materials, dredging, hypolimnetic aeration, to jointly approach the theoretical coverage of eutrophication control at related web-search publications. In parallel, our study is the first one, as far as we know, which has been focused on lake restoration research trends through the conducted bibliometric analysis, being expanded over the last decades of restoration techniques put into action. Furthermore, network maps were created in alignment with the literature review and the research quantification of: number of documents, trends, research teams, and citation frequency were identified and systematically recorded. The key-research determinants, the challenging issues, as well as the future prospects and research trends, they were further represented in the forms of keyword-clusters.

2. Materials and methods

2.1. Data source and search criteria

We broadly searched the Scopus database from 1970 to 2021, using the following terms: "eutrophication control"

OR "internal nutrient loads" OR "P-inactivation agent" OR "sediment capping materials" OR "phosphate removal in lakes" OR "lake alum treatment" OR "Phoslock". All search terms were restricted to studies published in the English language. This yielded 8601 results. The study selection and flow chart of the research framework are shown in Fig. 1.

It should be stressed out that the domain of mapping knowledge can be valued as a multi-disciplinary research method involving a broad variety of technical knowledge in mathematics, graphics, information visualization technology, metrology citation and concurrence analyses and methods. Such a multidisciplinary approach enables the utility of visual image maps unveiling disciples related to core structures, history, and frontier contexts. For the scopes of our study the VOSviewer research tool has been utilized, being specifically designed to detect and interpret emerging trends and abrupt changes in the field of literature production on eutrophication control and the role of shifting to invasive methods managing the internal nutrient loads.

VOSviewer is a software that analyzes publication data to create network maps. Specifically, it creates distance-based visualization in which terms that are more closely related are located closer together in the visual display [34]. This software was used to create a map of the co-occurrence of all keywords present among all the publications [35]. Full counting was selected to ensure that each keyword had the same weight as all other keywords regardless of the number of keywords per document. The minimum occurrence requirement for a keyword to be included in the map was selected to be 5. Only the top 34 keywords in the map were included, Fig. 1.

3. Results and discussion

3.1. Main characteristics of publication outputs

In this study, a plethora of article records were examined to gain the basic data and trends in the field of lake restoration. The total number of publications was 8601. This included 7,052 articles (82%), 361 reviews (4.2%), 933 proceeding papers (10.8%), 22 editorial materials (0.3%), 145 book chapters (1.7%), and other document types (<1%) (Fig. 2). Since 1990, the number of publications has increased significantly. Around 89.9% of the publications occurred during or after 2000 (Fig. 3). The average number of authors per document was 4.06. The total number of pages per year ranged between 18 and 14,182 (excluding years that lacked publications) with the average number of pages per document as 7.12. On average, these documents are cited 88.62 times per year when
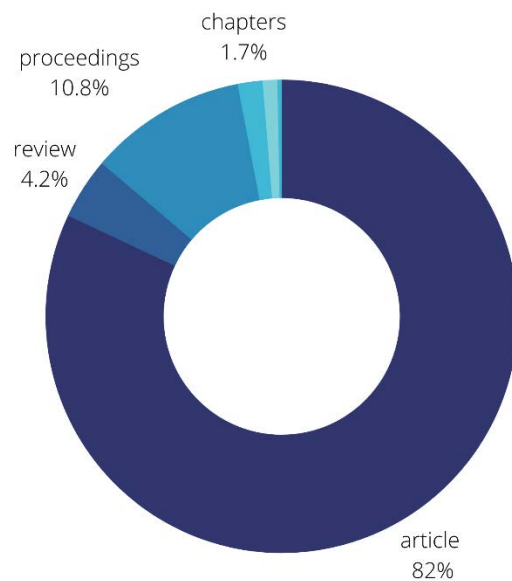

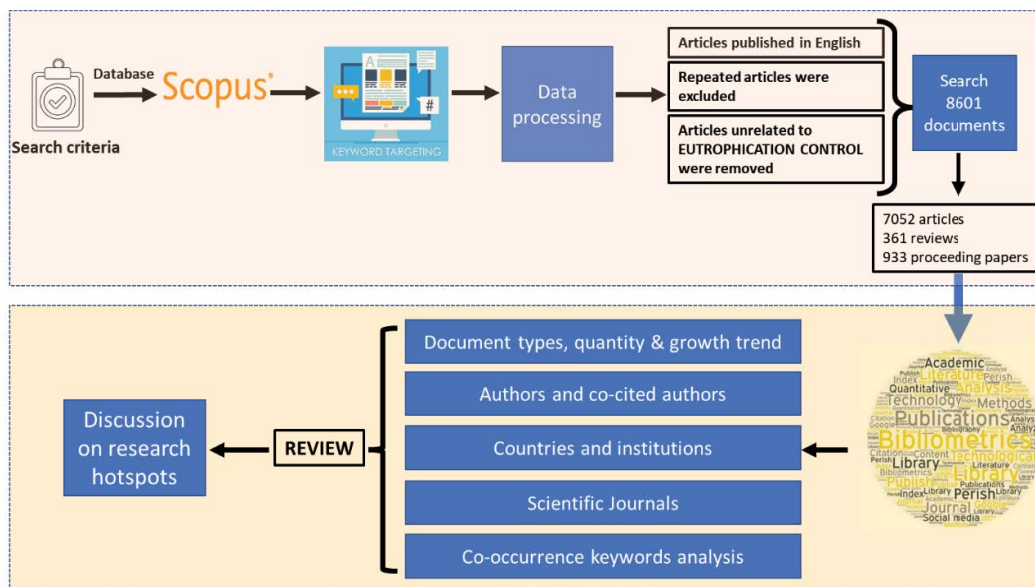Fig. 2. Types of documents represented in the literature (data from Scopus).

Fig. 1. Flow chart of research framework.

excluding the years that lacked publications or 108.44 times per year when all years are included.

Fig. 3 shows the number of papers on eutrophication control research published and the exponential trend line over time (the red line). The polynomial model described the relationship between the publication year and the number of publications. The number of papers has grown slowly, with no more than 50 papers per year before 1990. Since 2000, however, the number of papers has increased exponentially ($R^2 = 0.99$).

Earlier than 2000 the eutrophication was not considered as an utmost priority topic of investigation, but from 2000 onwards the eutrophication phenomenon has been steadily attracted research attention and scientific emphasis. This research swift can be attributed to the fact that from the year 2000 onwards it has been reported a notable economic rate growth among all countries worldwide, leading to ongoing phenomenon of eutrophicated water bodies and the consequent arousing research attention on eutrophication.

The number of papers exceeded through 100 in 2015 and 200 in 2016. In particular, 671 papers were published in 2021, with almost double the number of articles published in 2010 (343 papers). A total of 2,868 studies on eutrophication control were published in the last two years, accounting for 33.7% of all the included studies, Fig. 4.

3.2. Distribution of countries

A total of 129 countries published papers about eutrophication control and/or lake restoration of natural water bodies. Some of the 8,601 documents have authors from more than one country. Thus, the total number of records for all the countries and regions is 10,513. The People's Republic of China, the country with the most publications, published approximately 2,452 records or 23.32% of all sources while the second highest publishing country – the USA – published approximately 2015 records or 19.14% of all sources. This was followed by United Kingdom (5.36%), Canada (4.3%), and Germany (3.8%). It showed that China and the USA in this field were in the absolute superiority.
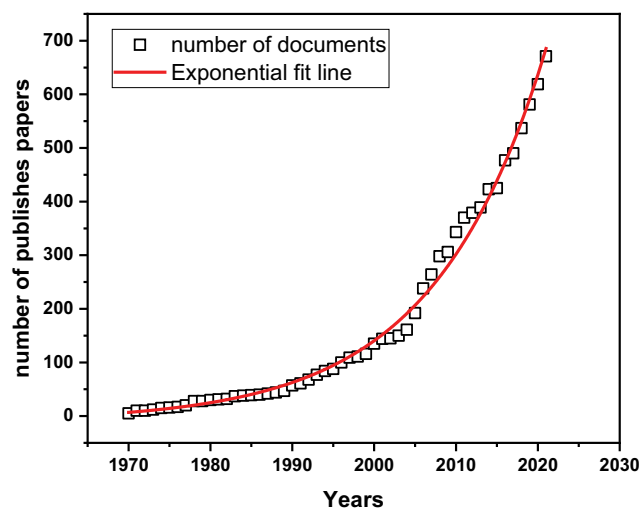
During the last years of analysis, it was shown that eutrophication gained ongoing research attention especially among Chinese scientists. Subsequently, research maturity and SCI-covered research achievements they received international attention. It can be also denoted that the Netherlands were ranked at sixth position, implying a solidified research interest in both eutrophication control and lake restoration, regardless the small population of the Netherlands. The top 15 ranking countries are shown in Fig. 4. According to the search criteria, 71 countries or 5.78% of sources published <10 records, and 342 records or 3.25% of the total number of records did not mention a country or region.

The per-country allocation of documents under the selected keywords, it is presented in Fig. 5. Based on the cloud word of Fig. 5 it was argued that six distinct clusters of international cooperation could be identified. Among them, the strongest collaboration has been reported in China and USA, in which various bilateral projects between central governments and scientific organizations, such as, that of the annual cooperative research project between the National Natural Science Foundation of China (NSFC) and National Science Foundation (NSF) – they have been funded and fostered the development of a powerful international cooperation, accordingly.

3.3. Distribution of journals

There were a lot of scientific journals publishing articles about lake restoration research through the analysis of the range of statistical articles. The documents were published in a total of 155 different sources. This wide spectrum of sources implied a broad distribution of the relevant journals-accommodated articles/documents. The top five sources that records were published in are listed below. The Science of the total Environment journal published the highest number of publications – 377 records or 4.38% of all records. This was followed by hydrobiologia with 257 publications or approximately 2.98% of all records and by the Journal Water Science and Technology with 224 records or 2.6% of all records. It can be, therefore, denoted the inverse order of journals' ranking with their

Fig. 3. Number of published papers per year (data from Scopus).
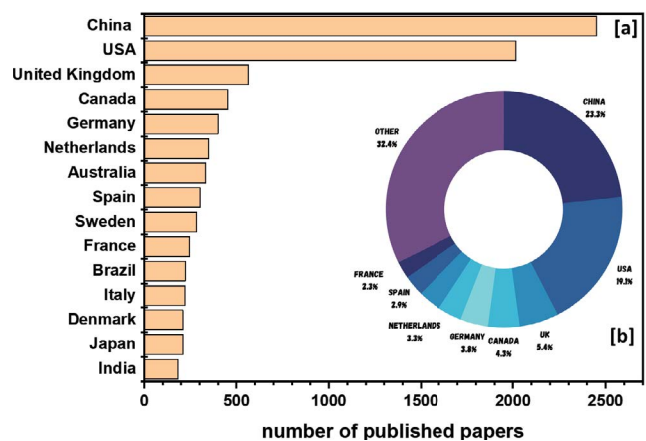
Fig. 4. Top 15 countries that published research related to eutrophication control and/or lake restoration (data from Scopus).
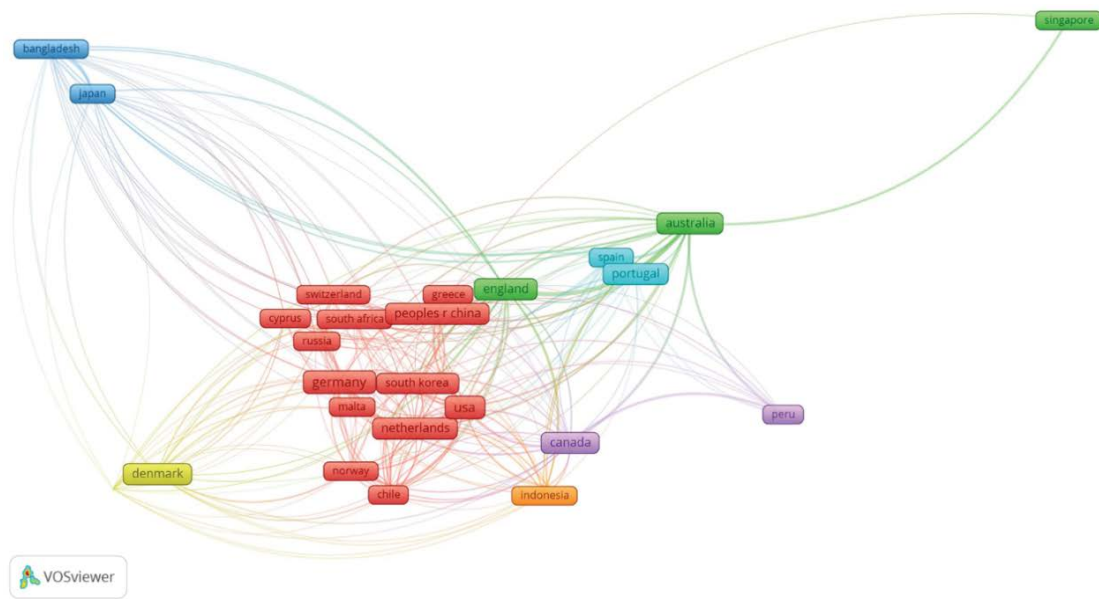
Fig. 5. The per-country allocation of documents regarding the present research.

corresponding publishing reputation, as it is the case of Water Research and Environmental Science and Technology journals, having impact factor of 5.528 and 5.330, while being ranked as 16th and 17th, in terms of the amount of published articles, respectively. Approximately 47 of all of the sources contained 20 or less records.

Approximately 13,067 different authors contributed to the 3,820 publication outputs. Fifty-two records (0.6% of all publications) did not mention an author (undefined). Approximately 78.1% of total, or 10,208 authors had contributed to only one source. The author who contributed to the most papers is E. Jeppesen, who authored/co-authored 53 or 1.36% of all publications. H.W. Paerl was an author/co-author in 48 or 1.10% of all publications. The next top publishing authors were M. Lürling, B. Qin, Z. Liu, and D.P. Hamilton, with 44, 35, 28, 24 publications respectively.

Overall, a total of 159 different institutions have been reported on research in the field of eutrophication control. Besides, it was observed that the most quantity of articles published at the period 1970–2021 in the field of eutrophication control, they can be allocated among the top 10 institutions, where the portion of 19.42% of the total published articles it has been published by a single institution, while the rest of 80.58% accounted by inter-agency cooperation.

3.4. Distribution of universities and institutions

The most ranking universities and institutions are listed in Fig. 6. The Chinese Academy of Sciences had the highest level of representation with 1084 publications or 12.6% of all sources. The number of articles from Chinese Academy of Sciences was in the first place, which showed that the
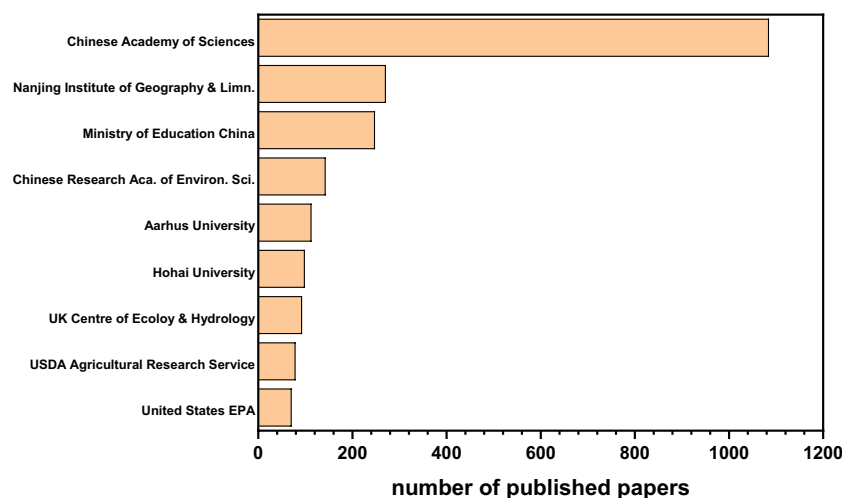

Fig. 6. Top ranking universities and institutions to publish research related to eutrophication control and/or lake restoration.

Chinese Academy of Sciences paid a high degree of attention to the research in the field of eutrophication control and lake restoration. Four institutions from China were in the top 10 institutions which had the most articles published in the world. It showed that not only there were a lot of institutions in China with strong ability of research in the field of lake restoration but also had a strong overall strength in lake restoration research.

According to Fig. 6, after the Chinese Academy of Sciences, the next five most highly ranking universities were the Nanjing Institute of Geography and Limnology Chinese Academy of Sciences, the Ministry of Education China, the Chinese Research Academy of Environmental Sciences, The Wageningen University & Research in Netherlands and the Aarhus University in Denmark. They were mentioned in 270 (3.13%), 247 (2.87%), 129 (1.5%) and 112 publications (1.3%) of all of the sources. The majority of the universities and institutions were mentioned 20 or less times. In fact, 44 of the institutions were mentioned 10 or less times, Fig. 6.

3.5. Distribution of keywords

To estimate the most common keywords used all publications were entered into VOSViewer. A total of 397 keywords were present in all of the records. Of this amount only 34 met the requirement of having 5 or more occurrences. The top 10 keywords based on link strength were as follows: eutrophication, phosphorus, sediment, restoration, nitrogen, release, lake restoration, Phoslock,

management, removal. The keywords are divided into 4 clusters or groups of closely related keywords. The color of the node represents the cluster to which it belongs, A map of the top keywords is present in Fig. 7. The size of the circle demonstrates how frequently the term was used as keyword in the different publications. The distance between terms indicates the frequency of two terms occurring together in either the abstract title or keyword listing of publications.

Fig. 8 is an overlay visualization map, showing keywords from 2000 to 2020. The yellower the color of the node in the figure is, the newer the keyword. The keywords near blue are as represent those that were proposed before 2005. It is clear that most of the keywords have emerged in the last 10 y, especially in the last five years. This may reflect that phosphate adsorption and lake restoration focusing on internal nutrient loads (sediment capping materials such as Phoslock) are a very new method.

3.6. Internal loading control

Based on Fig. 9 it can be argued that within the last two decades of analysis a steady increase in the use of sediment capping materials has been reported, functioning as preventing agents of phosphorus and nitrogen release from the sediment. In such a way these materials play a determining role of the regeneration of eutrophic phenomena at surface waters. Such indicative materials are that of Phoslock™, Alum, modified zeolite, modified bentonites,
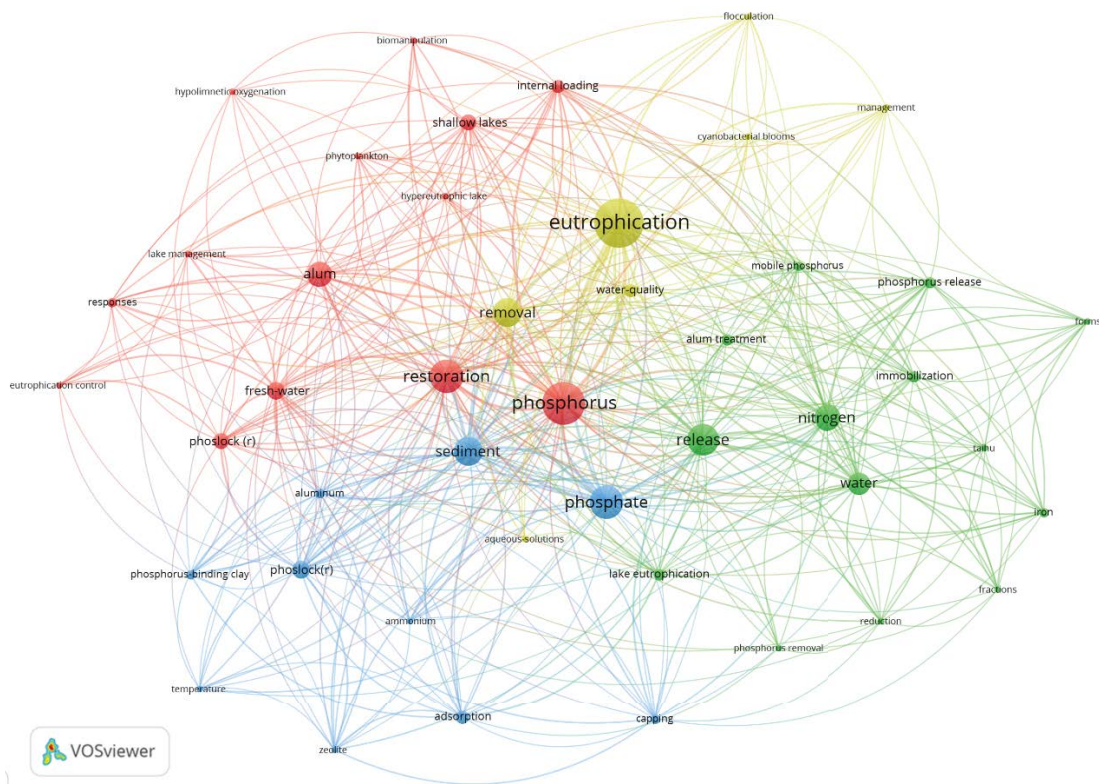

Fig. 7. Top keywords present in publications. Colors refer to different clusters or related topics. The bigger the size of the circle is, the greater frequency of the keyword. The closer the circles are, the more often the two keywords were found in the same publications.

Fig. 8. The overlay network visualization map of co-occurrence keywords for MP's research from 2000 to 2021.

Bephos™ and others [36–40]. At the same time there are also methods applied towards eutrophic environments restoration that are not supporting a particular upward trend over the years of analysis.

Another important finding is that dredging can be considered as a unique method available for to support the achievement of the ecological balance of lakes, in which contaminated sediments can be removed, enabling the internal loading reduction of nutrients. However, a critical factor of estimating the optimum dredging effectiveness it is the season selection, in particular at determining what is the exact time or period at which dredging activities could provide the maximum removal performance, while minimizing the concurring adverse effects. The experimental research of Zhong et al. [17] involved all four seasons in order the effects of dredging on the internal loading, and release from sediment of N and P were evaluated. These results indicated that dredging could be particularly capable at decreasing internal loading, while seasons with low temperature (non-growing seasons) are proven suitable at performing the operations proposed.

Phosphorous removal from the water column is also a critical and effective aspect to eutrophication control, while adsorption is proven one of the most competent treatment processes. Zamparas et al. [41] synthesized a P adsorbent of bentonite-humic material for which the sorption capability under different conditions evaluated. Subsequent a superior performance of P adsorption was deployed and various physico-chemical aspects of analysis, including adsorption kinetics, isotherms, and thermodynamic analyses of P by

as-prepared adsorbents were deployed and revealed the underpinning mechanisms. These mechanisms' effectiveness of modified bentonite for eutrophic water treatment owned its advantageous performance due to unique hierarchical porous structures, high adsorption capacity and low cost.

3.7. Research challenges and orientations

Based on the bibliometric analysis, above, it can be inferred that the highest number of publications in a country denoted that this was a country with the greatest eutrophication problem at those time. Besides, the profile of keywords reported for a country it identified what are the eutrophication stressors at those examined time and region(s) of the relevant analyses. Moreover it is noteworthy that, as any environmental problem, research on eutrophication demonstrated technologies and supported remediation problem-solving methods that are bounded on each time technological status and scalability perspectives of specific eutrophication instances. Therefore, the bibliometric-reported technologies and the methods adopted they should be considered as distinct and case-specific solutions that are impacting on those time know-how background and geographical characteristics, not be considered as aggregated "all-in" solutions. However, it remains challenging the easiness of adapting and transferring the same technological solutions of eutrophication from one water body to another globally, as well as the technological synergies developed among the today and the future technologies developed. The technological and the scalability prospects of future researches on eutrophication
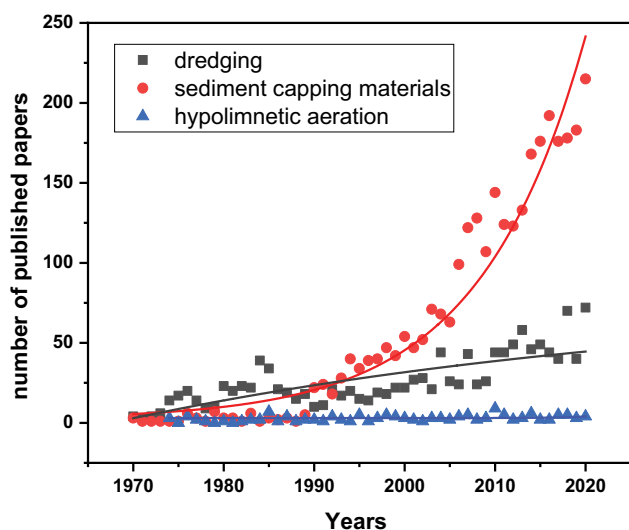
Fig. 9. Chronological profile of published papers in the field of internal loading control.

they can be considered as a combined techno-economical and societal problem, taking into consideration that authors of existing published papers they were primarily the ones who published the most on this eutrophication subject having accumulated the appropriate know-how expertise and receiving the relevant funding needed from their research/ solutions to eutrophication; either from the hosting academia/ higher education institutions, or from those organizations/ businesses participated and interested in. Therefore, besides to "technological/remediation synergies" there is need of "financial support and sponsorship" (especially among large scale remediation applications) under either private- and public-partnerships, or bilateral collaboration agreements, or corporate social responsibilities (CSR) schemes, or micro-financing by local banks (it is a popular source of local funding especially in emerging economies), respectively.

4. Conclusions

At this study the domain of eutrophication control by using the bibliometric method of evaluation was performed, while a comprehensive understanding of the research trends of lake restoration in terms of key-words publication outputs, countries, research institutions, subject categories, and publishing journals, they were presented and co-evaluated. Moreover, an innovative method-mapping knowledge domain analysis of keywords was applied to map the global research trends during the period of 1970–2021. These conclusions not only supported the cognitive extension of predecessor research achievements but also revealed useful information at the broader research areas of eutrophication control and lake restoration methods.

Based on the finding of the present work can be argued that within the last two decades of analysis a steady increase in the use of sediment capping materials has been reported, functioning as preventing agents of phosphorus and nitrogen release from the sediment. In such a way these materials play a determining role of the regeneration of eutrophic

phenomena at surface waters. Such indicative materials are that of Phoslock™, Alum, modified zeolite, modified bentonites and others.

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