AN ANALYSIS OF STUDIES ON NON-POINT SOURCES OF EUTROPHICATION DURING 1991-2023: A BIBLIOMETRIC APPROACH

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Abstract. Eutrophication is the gradual loading of nutrients in aquatic systems, and the non-point sources of pollutants have been a natural havoc in mitigating the effects caused by eutrophication. This study condenses various published works about the non-point sources of pollutants into a single study to present the global growth trend of the studies. A bibliometric analysis of the scientific outputs of the topic from 1991 to 2023 was conducted using the data from the Web of Science database. In this regard, 543 documents have been extracted and analyzed with Vos-viewer software and MS-Excel, which identified the growth of publication, most prolific author, most prolific journals, top funding organizations, co-authorship analysis, co-citation analysis, keywords, and SDGs oriented with them. The analysis found that the research in this area shows constructive growth, with China, the USA, and Canada as the most innovative regions with significant contributions. The Vos-Viewer network analysis displays a need for active collaboration and formal cooperation between authors around the globe. It will help bridge the current "non-point sources of pollution" research gap in every country by providing a systemic assessment of existing studies, research hotspots, and evidence to various stakeholders to shape the targets of SDGs.
Keywords: *VOS Viewer, wastewater treatment, scientometrics, constructed wetlands, SDGs*

Introduction

Aquatic ecosystem is a product of a delicate balance between the abiotic components and the various life forms which are present in the water system. Eutrophication is one such phenomenon that shows this imbalance in the water ecosystem consequently due to the increase in the amount of nutrients in a water system which triggers an ecological condition that leads to the growth of primary producers and ultimately to a decline in dissolved oxygen (DO) levels, causing hypoxia and anoxia (Vinçon-Leite et al., 2019). Eutrophication is considered as one of the most complex environmental issues globally (Yang et al., 2008). It is observed that eutrophication can occur naturally, however, human intervention and its activities have immensely accelerated the process aggravating its effects in the natural way of the water ecosystem (Ansari and Gill, 2014). The

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centrality of the problem can be dated back to the 1970s when Schindler (1974) prompted about the large inputs of nutrients due to anthropogenic activities and his efforts to control the culturally (human-aggravated) eutrophied lakes in Ontario (Canada). Besides inland water systems, the problem extended even upto the estuaries and the coastal regions of S. San Francisco Bay in the USA (Officer et al., 1982). Therefore, cultural eutrophication still serves as the major quality issue of water in most of the water bodies - both freshwater and marine ecosystems (Smith et al., 2009).

The major nutrients for the algae, bacteria, protozoa, and other aquatic organisms that make up the surface water ecosystem are nitrogen (N) and phosphorus (P). However, excessive loading of these nutrients into the water bodies may result in eutrophication. Even though there is a natural way for eutrophication to occur, it is obvious that the eutrophication we observe today is mainly the product of human activities. In a study by Yang et al., (2008), it was shown that due to the population increase in the catchment area and its associated phosphorus influx from the drainage systems, Lake Greifensee, Switzerland, went from being oligotrophic 120 years ago to becoming hypertrophic in the early 1970s. These sources of nutrients and anthropogenic pollutants can be identified into Point Sources and Non-Point Sources (NPS) broadly. The recognizable sources of water contamination, such as stationary or immovable locations, are referred to as point sources. Besides the industrial sewage and effluents, many intensive agricultural units like animal farming units in the UK and USA have also proved to be a significant point source of nutrients to the water bodies (Harper, 1992). Whereas, in the non-point sources of pollution, not only its complexity in addressing the sources, control, and management of these classes of pollutants has also proved to be more menacing since it is difficult to control excess runoff water (Ansari and Gill, 2014). Non-point sources vary spatially and temporally with different factors like rainfall, climate, and other irregular events taking place in an area.

Phosphate and nitrogen from non-point agricultural sources are considered one of the important causes of surface water eutrophication. One of the key factors contributing to the global eutrophication of rivers and lakes is the widespread use of phosphate-based detergents. In the case of Lake Chagan in China, agricultural waste surface runoff anthropogenic factors around the lake regions are the key factors in its eutrophication (Ge et al., 2023). Subsequent atmospheric deposition of the gaseous nitrogen emissions can constitute a predominant source of nitrogen in the downwind regions (Scheer et al., 2001). Aggravated temperature and climate change lead to more microbial growth of cyanobacteria. The self-purification capacity of the water is also greatly decreased due to the rise in the temperature of the water (Nazari et al., 2018). It also shows the effect of the alteration of regional precipitation patterns, which leads to water quality deterioration since the water is exposed to more nutrient loads. Besides these, the authors in this paper shows the contribution of change in sunlight and wind patterns to make the water body oligotrophic.

The role of non-point sources in eutrophication is far more significant as compared to the conventional sources of nutrients. These sources exaggerate the ill effects of nutrient contamination as the control and prevention of the contaminants is difficult to point out. Evaluation of published scientific research on the non-point sources of pollutants will help to understand the research trend and the main stakeholders in this field socially, financially and intellectually. This study intends to analyse the published scientific literature in the field of nutrient pollution in water based on bibliometrics parameters.

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Bibliometrics, as a process, was introduced as early as 1922 to analyze data visually and summarise the trends in respective research fields (Pritchard, 1969). The objective and scientific approach to quantify the research products of this field will help the researchers to frame new objectives and research on emerging areas (Basumatary et al., 2022). Besides the traditional way of literature review, it will also help academicians analyze the data and strategize their research areas to refine the scientific realm of the field. Although the bibliometric and scientometric analysis have been performed about the output of publications of different countries and authors (Yanhua et al., 2012; Li et al., 2014; Gao et al., 2015; Xiang et al., 2017; Yao et al., 2018), there are no proper studies which covers the scientific cooperation between different authors which includes aspects of the co-authorship and the co-citation analysis of the different authors. One of these studies gave the importance of bibliometric studies which are being done in many research fields- climate change, air pollution, carbon cycling, estuary pollution, aquatic ecosystems, etc. (Yao et al., 2018). A comprehensive analysis depicts the process how subfield analysis can help in the profound research of Climate Change (Haunschild et al., 2016). It also highlighted the different realms of studies which can be studied in the future regarding the nitrogen pollution in eutrophic lakes. However, the study was concentrated on only the nitrogen sources in an older time frame i.e. from 1991-2015. In addition to this, there has been no comprehensive study which linked the “Non-Point Sources” and “Eutrophication”. This paper aims to fill that gap and analyse the global participation in the research of this area. Based on this, the objectives of this study are framed as follows:

i) To find the growth of publications and establish the growth trend;
ii) To identify the most prolific countries;
iii) To pick out the top funding organizations;
iv) To identify the most prolific authors;
v) To identify the most prolific journals;
vi) To analyse the authorship collaboration and co-citation between the authors;
vii) To determine the most prominent keyword and visualize the co-occurrences of these keywords.

Materials and methods

Reviewing a particular domain systematically helps us speed up the review work for research. The scientometric tool of bibliometrics is an easy and one of the appropriate tools to measure the growth trend in research activities. The study helps to arrange the way ahead of the waste-water research and mitigation. Bibliometric analysis can help in the identification and innovation of new thematic patterns, research performance, research productivity, build-up of the cognitive structure and dynamic topic modelling (Kim and Zhu, 2018). Regarding this study, the bibliographical data of published works from 1991 to 2023 from Web of Science (WOS) core collection database. This includes all the documents which were listed in the publishers indexed in SCI-E (Science Citation Index Expanded) and SSCI (Social Sciences Citation Index). The search term used were “Non Point Sources” and “Eutrophication” in the “All Fields” section to export the bibliographical data in ‘Plain Text file’ format which covers the full record and the cited references of the documents. The categories of documents included in the analysis are “Research articles”, “Review articles”, “Book chapters”, “Proceeding paper” and “Early access” publications. However, “Editorial materials” were excluded in the analysis as editorial publications often lack a proper methodology of study and sometimes even tends

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to be biased in nature. The data is exported, cured and organized into MS-Excel format for calculation and analysis of the chronological publication and citation growth trends. VOS-Viewer Software (VVS) is used for data export, scientific mapping and network visualization to perform Co-authorship analysis, Co-citation analysis and keyword analysis.

Results

The search field exported 543 bibliographical data as indexed on 30-11-2023. The data were analysed with MS-Excel to give the following results.

Eutrophication has been a menace that have significant effects in the cycle of different wetland systems. There have been various studies which documented and suggests various counteractive activities to control the trophic status of the water bodies. It can be undeniably demonstrated that enrichment with either N or P can raise autotroph production; however, in almost all cases, synchronous enrichment with both nutrients resulted in significantly greater production levels (Elser et al., 2007). In the Web of Science database, research publications were first indexed in 1991 (Web of Science; Sekine et al., 1991) and starts notable growth from 2000s.

It is observed (*Fig. 1*) that the growth of research publications accelerated significantly from the year 2010 onwards, which shows a momentous increase in the research regarding Eutrophication and its NPS. The illustration of research growth is depicted as line chart (*Fig. 1*) in which the growth trend shows an exponential growth trend line with R-squared (r^2) value of 0.9514 (≈1). This implies that there is significant production of literature during the study timeline taken i.e.1991-2023. Besides this, the forecast growth of publications can range from 42 documents (lower confidence) to 82 documents (upper confidence) in 2032 with a 95% level of confidence as per the statistical analysis done in MS-EXCEL. The different lines in the figure shows the range in which the number of publications can fall within the range in this level of confidence. The red line depicts the highest potential outcome in an optimistic approach while the white line conversely gives the conservative estimate of future publications. The quantitative analysis and forecasting of publication growth is an essential step for young researchers and scientists to make conducive decisions about their studies.

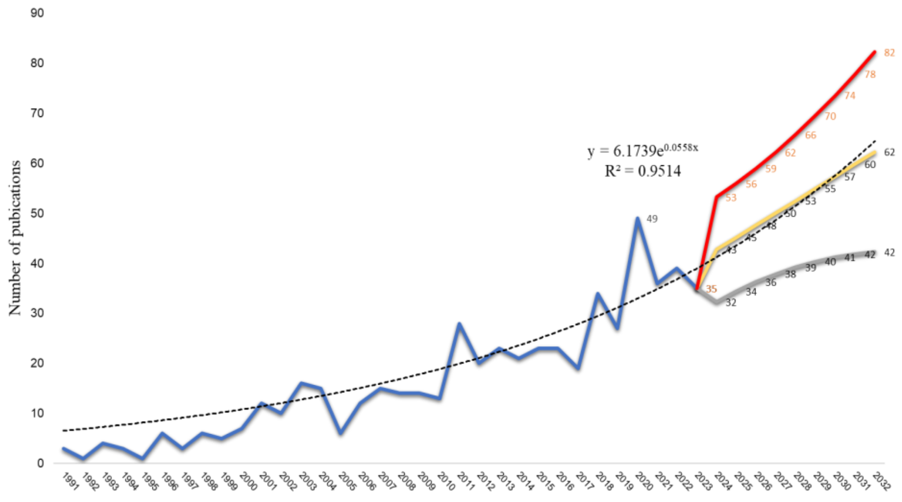

Figure 1. *Publication growth trend and forecast for the next 10 years*

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Most prolific countries

China accounts for the largest share of 182 documents (34%) followed by USA (157 documents-30%) and Canada (50 documents-9%). As shown in *Fig. 2*, China and the USA evidently have the maximum share with a cumulative global share of 64% of the total publications all over the world in this realm. However, Australia has the maximum citations per document, although China and the USA have the maximum research output. China is behind in citations and needs appropriate improvement in the quality of its journals, as per this analysis. This is also evidently shown by previous studies which suggest enhancement in the research output from China regarding eutrophic lakes (Yao et al., 2018) and phosphorous research (Gao et al., 2015). In the global context, Europe stands for the maximum share of research outputs. As for Asia, South Korea and Taiwan contribute an ample amount of research studies next to China. Despite India having 80 Ramsar sites, including 3 of them in the Montreux records, the studies regarding the anthropogenic non-point factors of eutrophication are very limited in this regard. India accounts only 2% (10 documents) in the global share, and these studies emphasized the need for biological treatment, bioremediation, incorporation of remote sensing techniques, etc. and suggests for a more sustainable move like the Ganga Action Plan in the country.

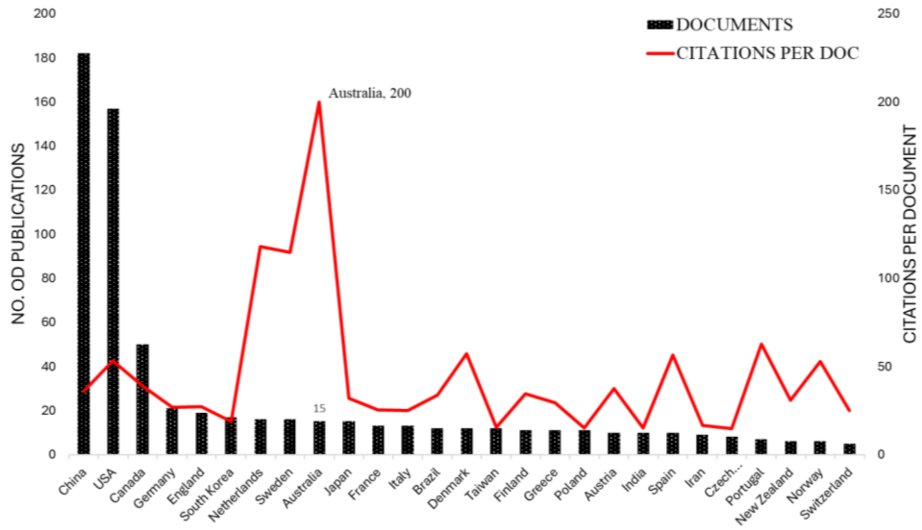

***Figure 2.** Country-wise publication and citation*

Most prolific funding organizations

The top ten organizations which immensely helped in the funding of the research in this field are listed in *Table 1*. The National Natural Science Foundation of China funded and assisted in researching and publishing 91 documents. Out of the top ten funding organizations in the world, five of them are from China. This may explain why China leads globally in producing research outputs. Next to China, the USA has the maximum funding for research as per the analysis performed. A previous study has already mentioned that fund grants have a positive effect on the research outputs quantitively and qualitatively (Chudnovsky et al., 2008). A study conducted in Argentina suggests the policymakers of emerging economies design policy instruments to potentially give more

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fruitful social returns and also scientific collaboration (Ubfal and Maffioli, 2011). It is, therefore, indispensable to analyze the institutions which are funding the research in this area and plan the future scopes of the study accordingly.

Table 1. *TOP 10 Global Funding Organizations*

Funding Organizations	Documents associated
National Natural Science Foundation of China, CHINA	91
National Science Foundation, USA	22
National Key Research and Development Program of CHINA	17
Chinese Academy of Sciences	14
European Union	11
Fundamental Research Funds for The Central Universities, CHINA	11
Natural Sciences and Engineering Research Council of CANADA	11
National Basic Research Program of CHINA	9
United States Department of Agriculture, USA	7
NSF Directorate for Biological Sciences, USA	6

Most prolific authors

The most prolific authors in the research field are depicted in *Table 2* where the top 10 publishers are ranked according to the number of publications, total publications, citations and h-index. Hongbin Liu (NP=8, TP=264, TC=6319, h-index=40) from Chinese Academy of Agricultural Sciences has the maximum of publications in this field and tops the list. Almost all of the authors in the top ten collection around the globe are Chinese affiliated with universities from China presently or in the past. However, GB Arhonditsis (NP=6, TP=196, TC=6281, h-index=43) from University of Toronto Scarborough, Canada has the highest h-index as per the WOS database of top 5 authors.

Table 2. *Most Prolific Authors*

Authors	NP	Organisation & Affiliation	Country	TP	TC	h-index
Hongbin Liu	8	Chinese Academy of Agricultural Sciences	China	264	6319	40
J Liu	7	Wuhan University	China	61	670	15
GB Arhonditsis	6	University of Toronto	Canada	196	6281	43
Yong Li	6	Chinese Academy of Sciences	China	65	1952	26
SA Ludsin	6	The Ohio State University	USA	119	4500	37
LM Zhai	6	Kanagawa University	Japan	98	3449	34
JF Martin	5	Ohio State University	USA	64	1632	24
HY Wang	5	Tongji University	China	142	2088	17
H Xu	5	Argonne National Laboratory	USA	25	482	14
Billen G	4	Sorbonne University	FRANCE	96	10896	56

NP-No. of Publications, TP-Total Publications, TC-Total Citations

Most productive and prolific journals

The most productive and prolific journals in the study of wastewater pollution research due to non-point sources of pollutants are enlisted in *Table 3*. There were 193 journals listed in the WOS Clarivate Master journal list, of which 28 had at least 5 publications regarding the subject matter. Among these journals, “Science of the Total Environment” published by Elsevier- Netherlands had the maximum output with 34 documents, TC of 1151, and JIF_{2022} of 9.8. It is followed by “Water Science and Technology” (NP=34,

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TC=339, JIF_{2022}=2.7); “Environmental Science and Pollution Research” (NP=20, TC=276, JIF_{2022}=5.8); “Journal of Great Lakes Research” (NP=18, TC=398, JIF_{2022}=2.2) and “Water” (NP=14, TC=79, JIF_{2022}=3.4) as top 5 journal sources ranked according to the number of the documents published with respect to this research realm. Most of the notable publishers in *Table 3* belonged to the Elsevier-Netherlands (3 documents) trailed by Springer- Netherlands (2 documents) in the second place. The originating country for most of the publishers belonged to the European countries like Springer-Germany, Springer-Switzerland, Elsevier-England, MDPI- Switzerland and IWA-publishing-England with 1 document each in the top 10 contributors.

Table 3. *Most Prolific Journals*

SOURCE/JOURNAL	NP	TC	TLS	Quartile	Publisher-Country	JIF(2022)	SP
SCIENCE OF THE TOTAL ENVIRONMENT	34	1151	30	Q1	ELSEVIER- NETHERLANDS	9.8	1972
WATER SCIENCE AND TECHNOLOGY	24	339	3	Q2	IWA PUBLISHING-ENGLAND	2.7	1981
ENVIRONMENTAL SCIENCE AND POLLUTION RESEARCH	20	276	11	Q1	SPRINGER-GERMANY	5.8	1994
JOURNAL OF GREAT LAKES RESEARCH	18	398	5	Q1	ELSEVIER-ENGLAND	2.2	1975
WATER	14	79	5	Q1	MDPI-SWITZERLAND	3.4	2009
WATER AIR AND SOIL POLLUTION	14	387	4	Q2	SPRINGER-SWITZERLAND	2.9	1971
ENVIRONMENTAL MONITORING AND ASSESSMENT	13	235	5	Q2	SPRINGER-NETHERLANDS	3	1981
HYDROBIOLOGIA	13	1471	14	Q1	SPRINGER-NETHERLANDS	2.6	1948
JOURNAL OF HYDROLOGY	13	263	8	Q1	ELSEVIER- NETHERLANDS	6.4	1963
AGRICULTURE ECOSYSTEMS & ENVIRONMENT	11	447	9	Q1	ELSEVIER- NETHERLANDS	6.6	1982

NP-No. of Publications, TC-Total Citations, TLS-total linking strength, JIF-Journal Impact Factor and SP- Start of Publications

Co-authorship between different countries

The co-authorship analysis is being performed as it is considered one of the concrete instances where the countries or authors show a formal appreciation of cooperation between them. The analysis showed that 27 countries out of 70 countries have at least 5 publications and share the most collaboration relationships. The collaborated countries are observed to form a network map as in *Fig. 3(A)* and form 6 clusters of different colours. Clusters are formed in a manner such that the frequency of co-occurring terms which represents each country. The VVS analysis gives the network visualization map in such a way that the size of the circles shows the number of publications in the country and the size of the nodes connecting the countries shows the level of collaboration. In this analysis, Cluster 2 (Green), with China and the USA, has the maximum share of collaborators and the biggest number of publications. The countries which collaborate with this cluster are Greece, New Zealand and Taiwan. Next to this, Canada and its collaborators in the cluster 4 (Yellow) stands in the second place. This Cluster includes Germany, Netherlands and Brazil. Besides this, Cluster 1 (Orange) have the maximum number of collaborators which consists of Denmark, England, Finland, Italy, Portugal, Spain and Sweden. Therefore, the maximum of collaborators in this cluster are from Europe that signifies a healthy collaboration between the institutions in the European countries. The network map in *Fig. 3(B)* shows that the temporal change in the publication output of the countries which signifies the older outputs were from USA and China is the maximum contributor in this research realm. The overall analysis shows that the all the countries have good collaborative relationship and closely knitted with one another. This can effectively give more scientific achievements and sharing of country’s resources for a greater cause of mankind.

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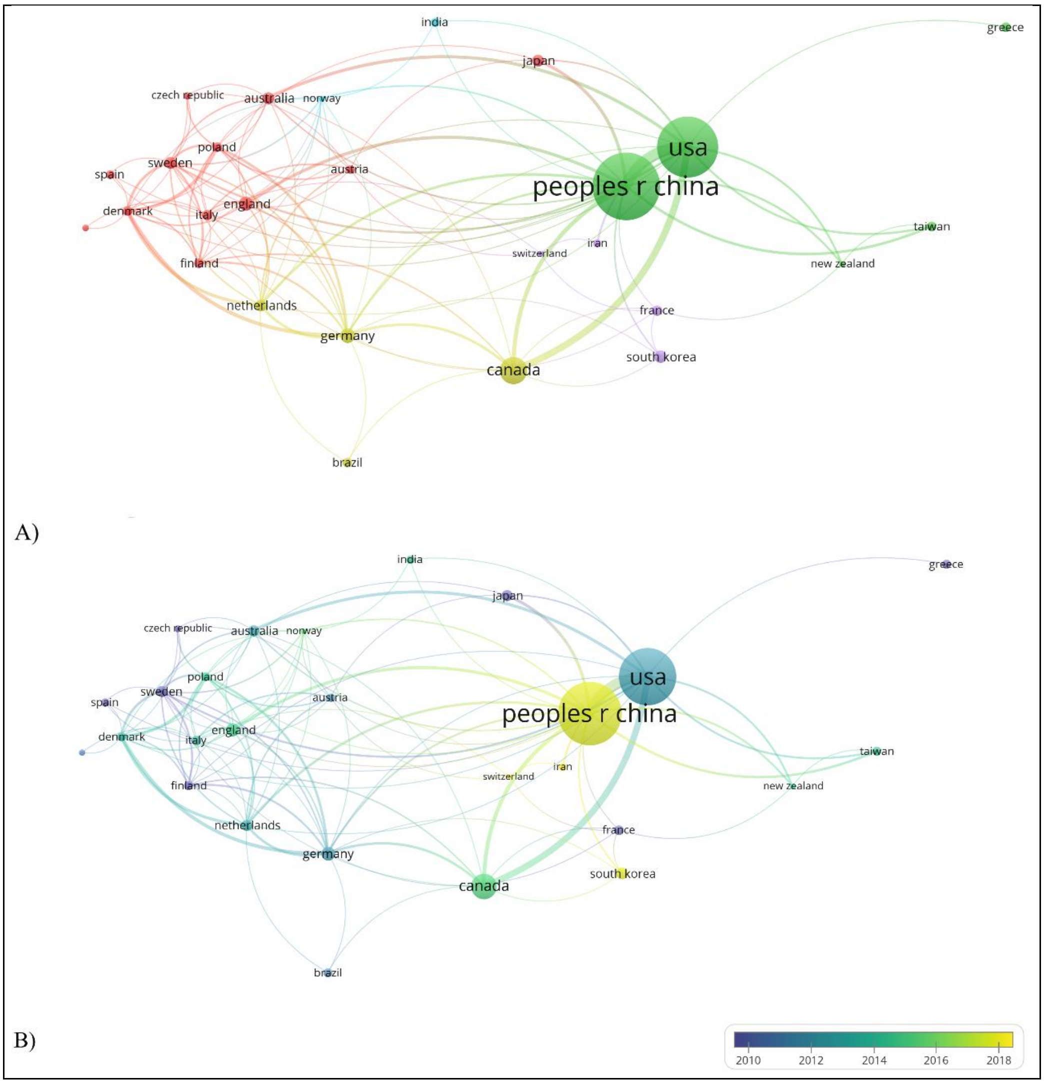

Figure 3. *A) VVS Network Map showing Co-Authorship Analysis for countries; B) VVS analysis showing overlay Visualisation of Co-authorship Network map*

Co-authorship between different authors

The co-authorship analysis can give a picture of how the authors from different parts of the globe can interact so that they can increase their impact in their research realm. Past studies have reported that co-authorship can be associated with authors who want to expand their scientific atmosphere and increase their formal association so that their publications are productive; quantitatively and qualitatively. *Fig. 4* shows the minimal amount association of authors in the field of eutrophication and its non-point sources as per the VVS analysis. The analysis shows 10 clusters with different colours. Cluster 1 (Red) and Cluster 2 (Green) have the highest number of authors with 6 authors in each cluster. Each cluster is observed to work independently within their own cluster and there is no sign of linkage between the clusters. Hongbin Liu (NP=8, TP=264, TC=6319, h-index=40) and from Chinese Academy of Agricultural Sciences has the maximum Total linking Strength (TLS) of 17 and collaborates with Shufang Guo, Quilang Lei, Jian Liu,

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Hongyuan Wang and Limei Zhai. Cluster 2 with Stuart A Ludsin from The Ohio State University is the second most collaborative author with TLS of 16 after Hongbin Liu.

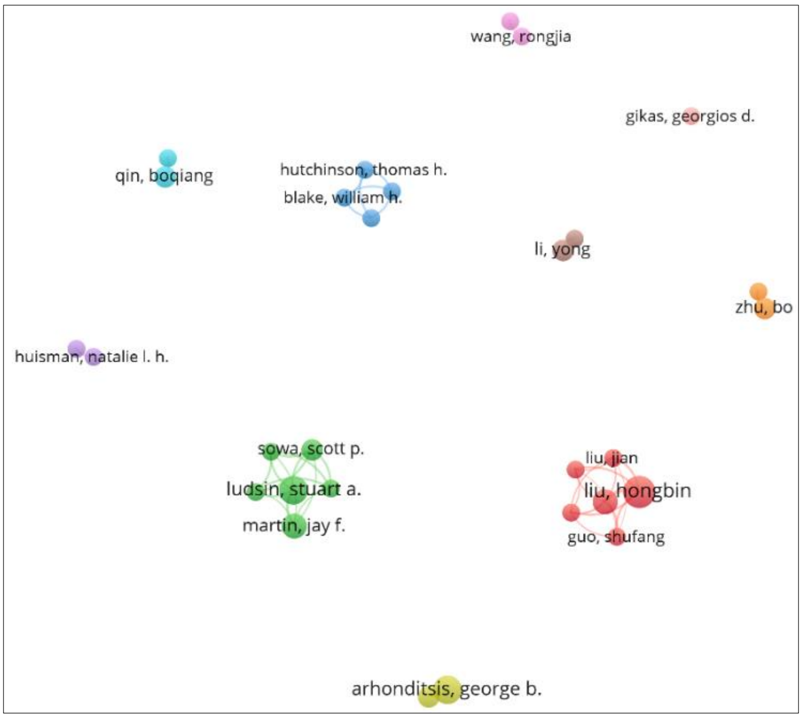

Figure 4. *VVS Network map for Co-authorship analysis of different authors in Eutrophication research*

Co-citation between different authors

Co-citation analysis is a significant procedure to understand the relationship between the cited publications of different authors. Here, VVS analyses the references of the documents and give a network map of how the authors co-cited different papers and arrange these documents thematically. It provides researchers with the advantage of allowing them to identify thematic clusters in addition to the most important publications (Donthu et al., 2021). By analysing the co-citation pattern of the literature, we are able to trace the intellectual structure of the world (Calabretta et al., 2011; Mendes et al., 2018). As per our analysis, there were 16767 authors which were cited in the data set. Out of this, 235 authors meet the threshold of at least 10 citations, and VVS analyze this data to make a visualization (*Fig. 5*). The cited authors are grouped as per the amount of occurrence in the dataset and their TLS. There were 6 clusters: Cluster 1(Red), Cluster 2 (Green), Cluster 3 (Blue), Cluster 4 (Yellow), Cluster 5 (Purple) and Cluster 6 (Azure/Sky-blue). Hw Paerl of Cluster 2 is ranked 1 among the 235 authors with a TLS of 1844 and cited 114 times in the dataset. The Top 5 authors are: i) HW Paerl, University of N. Carolina, USA ii) A. N. Sharpley (TLS=1740), University of Arkansas System, USA iii) Stephen R Carpenter (TLS=1267), University of Wisconsin Madison iv) VH Smith (TLS=1164), University of Western Ontario, Canada, and v) David W Schindler (TLS=1161), University of Alberta, Canada. However, the top prolific authors cannot be observed in this list and it may be due to their low linking strength.

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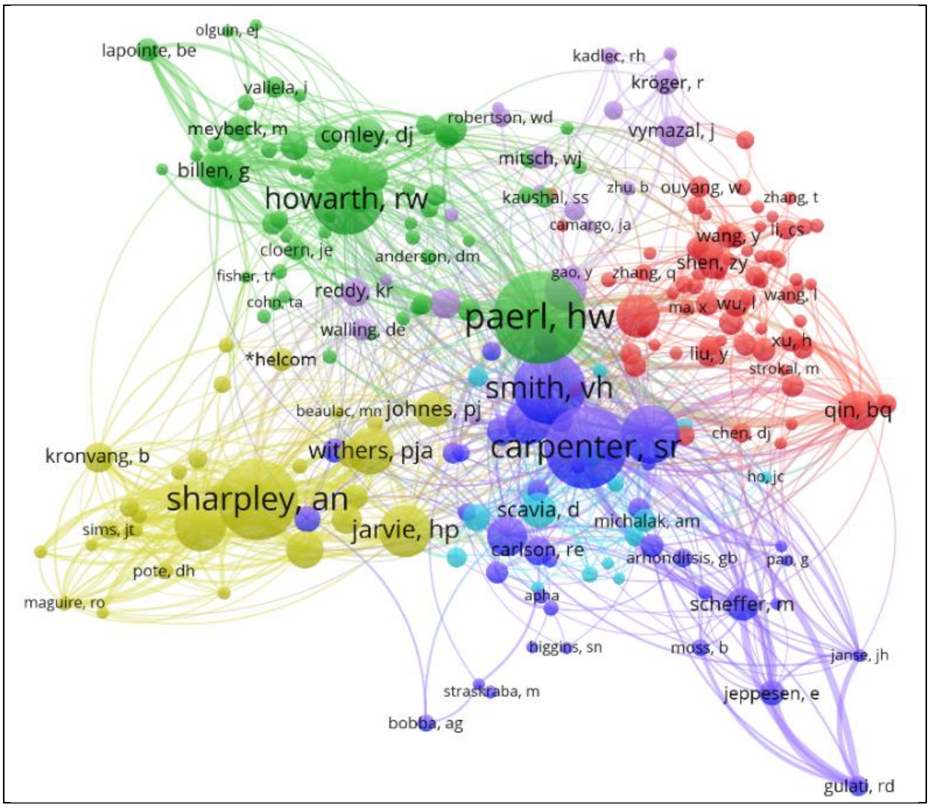

Figure 5. *VVS Network map for Co-citation analysis of different authors*

Keyword analysis

As per the keyword analysis, we obtained 2977 keywords, out of which 216 keywords have occurred 5 times at least. The word "Eutrophication" occurs the maximum number of times (292) with a TLS of 1686 and was found co-occurring with "climate change," "constructed wetlands," "trophic state index," "Chesapeake Bay," and 33 other keywords as observed in *Fig. 6*. The list in *Table 4* shows the Top Ten keywords along with their linking strength. The VVS keyword analysis gives 6 Clusters where we can analyze the importance/ weight of research of each keyword in this discipline. "Eutrophication" is the most prominent keyword since all the bibliographic entries in the data are related to it directly or indirectly. After "Eutrophication," "Phosphorous," and "Nitrogen" are the subsequent keywords used, which emphasizes their dominance in the production of research documents about these two nutrients. Nitrogen and phosphorous through leaching or run-off from agricultural lands continue to be the top contributing non-point source of nutrient pollution (Wang et al., 2019). A group of researchers also studied the various control measures of these non-point sources and encouraged the source-control measures and hybrid constructed wetlands with appropriate government initiative for an effective mitigation step (Xia et al., 2020). Another study also covered the use of both SWAT (Soil and Water assessment tool) modeling and WLA (Waste load allocation) techniques could give a low cost sustainable technique to monitor and control the non-point source pollution (Imani et al., 2017). The keyword analyses help us link with new keywords and other vulnerable ecosystems, which will greatly help new researchers and scientists.

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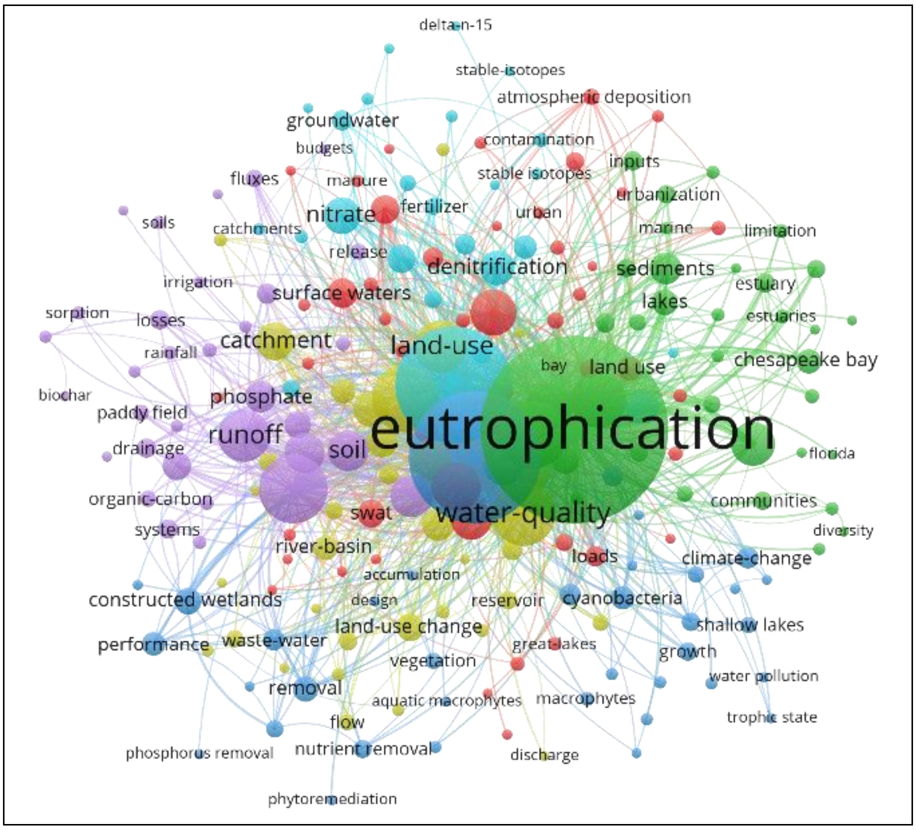

Figure 6. *VVS network map for Keyword analysis showing the relative strength of each Keyword and Co-occurrence*

Table 4. *TOP 10 Keywords associated with Eutrophication and its Non-point Sources*

Keyword	NC	TLS
EUTROPHICATION	292	1686
PHOSPHORUS	177	1129
NITROGEN	149	1025
NON-POINT SOURCE POLLUTION	70	475
WATER QUALITY	70	446
MANAGEMENT	69	419
WATER-QUALITY	63	433
NUTRIENTS	52	352
LAND-USE	48	341
RUNOFF	48	320

NC-No. of Citations; TLS-Total Linking Strength

SDGs oriented

The study incorporates the linkage of SDGs with the scientific literature in this field. We can examine the number of documents that follow the framework of the SDGs. *Fig. 7* shows the Tree diagram of the SDGs linked with the study and their respective weights in this area. The top 5 SDGs mentioned are: i) SDG06: “Clean Water and Sanitation,” ii) SDG13: “Climate Action,” iii) SDG15: “Life on Land,” iv) SDG14: “Life below Water,” and v) SDG02: “Zero Hunger.” However, the ambiguous nature of SDGs needs more refining and proper channelization.

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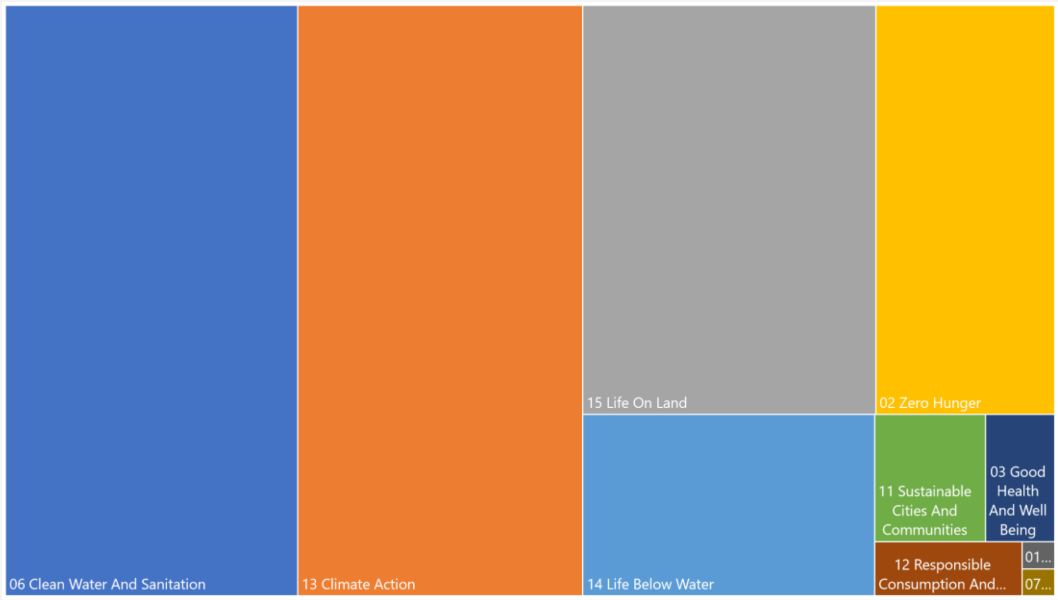

Figure 7. *SDGs oriented with Eutrophication and its Non-point sources*

Discussion

The present study incorporates the research in the nutrient pollution/recovery of water and helps us study the growth of research. A prospective bibliometric analysis of the past-present literature is one of the pragmatic ways to explore the links between different stakeholders regarding this discipline (Kamilya et al., 2022). It also encompasses the funding and financial environment of research in different countries. The investigation also analyses the intellectual structure of the research realm, which can be analyzed through co-authorship, co-citation, and keyword analysis. This process can serve as a critical step in attracting the right audience and help researchers to understand their field thereby giving rise to more impactful research.

The growth of publication in the current field shows a healthy research environment and trend. Our investigation shows that Eutrophication has been a global menace which has a humongous factor in deteriorating water qualities (Khan and Mohammad, 2014). Nonetheless, it has also helped shape ecological biomes, nutrient loading, carbon sequestration, etc. It's vital to see eutrophication not only as a nutrient pollution problem but as a situation where an increased supply of organic matter exists in an ecosystem. It is worth studying the dynamics of different nutrients and their management for their cumulative effects in the restoration of wetlands (Schindler, 2006). The research growth is promising as the number of publications is rising as the regression analysis of the growth curve is significant. This growth should be properly planned and critically designed so that the mitigation techniques are efficient and sustainable. There should be appropriate monitoring of the nutrient status with the integration of traditional methods and recent technologies like multi-spectral imaging and 3-D mapping of water quality as done in a study reported by a group of scientists from China (Li et al., 2021). This can be explained by the rising number of cases of wastewater due to improper urban planning and indiscriminate use of chemical inputs in agriculture and allied activities. With the rise in population size, there has been an exponential rise in cultural eutrophication. Developing and Under-developed countries have minimal facilities for sewage treatment

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plants. There is a need for constant monitoring and assessment of the water quality to find the hotspots of non-point nutrient sources (Hietala et al., 2024). Therefore, the rising cases of wastewater research is inevitable for every institution in every country. The unsuitability of the conventional methods of wastewater treatment techniques due to high energy consumption, high costs, huge infrastructure, and capital investments should be the primary drive to discover techniques like 'Constructed Wetlands'. Constructed Wetlands, a cost-effective and emerging technology, help in countering nutrient and heavy metal pollution (Vymazal, 2011; Kumar et al., 2023; Herrera-Navarrete et al., 2022). The study of macrophytes and plants for a cheaper and sustainable phytoremedial technique to combat eutrophication is of primary importance (Rai, 2008). The keyword analysis helped in the acknowledgment of a commendable initiative in Chesapeake Bay of how the successful implementation of the Anti-Pollution measures curbs the non-point sources of nitrogen loading into its fragile coastal ecosystem (Pan et al., 2021). The study further used the technique of DLEM (Dynamic Land Ecosystem Model) along with MOSART (Model of Scale Adaptive River Transport) to observe the rate of different Nitrogen forms into the water system. Therefore, with accurate data collection, investigation, and a proper strategy from the State, we can incorporate the robust use of this DLEM model to predict the environmental dynamics of various vulnerable ecosystems countering its deterioration sustainably (Tian et al., 2009).

The co-authorship between countries is relatively strong. The European States, which include Denmark, England, Finland, Italy, Portugal, Spain, and Sweden, show the greatest cluster of countries that share co-authorship. This may be due to easier interaction between the countries under a common Economic Union, co-governance, geographically clustered, relatively common culture, language, and society (Jaramillo et al., 2023). It is also in line with a study performed, which showed that a collaborative governance of adjoining provinces in China helped foster healthy cooperative and innovative research regarding pollution in the Yangtze River Delta area (Jaramillo et al., 2023). India shows maximum co-authorship companionship with Norway, China, and the USA. This is in concurrence with a report in 2023 that China and the USA are the leading collaborators of the country, and its international association has grown noticeably in the past 2 decades (Dua et al., 2034). The same study encouraged a more significant domestic collaboration to strengthen the core research areas, productivity, visibility, and hence more impact of the research institutions in the country. India needs more institutional teamwork in this regard to maneuver proper funding, infrastructural support, and intellectual expertise and, hence, develop efficient techniques that are feasible in its economic framework. It is interesting to note that Lathabai et al. (2022) provided a clear understanding of how institutions need to coordinate amongst themselves to scale up its capacity building and quantify further novel studies. Authors around the world and the country need to connect more formally sharing their intellectual sphere to combat the wastewater problems caused by non-point sources. The wide coverage of co-authorship analysis spanning across various fields can help in the interdisciplinary analysis of the research (Uddin et al., 2012). The VOS Viewer network map (*Fig. 4*) shows a visible ghettoization of authors, and this is a primary blunder which may retard the development of efficient and cheaper technologies of wastewater treatment and reduction. Besides all of this, the study helped us to depict the number of documents that openly connect them with SDGs. Linking of studies with SDGs help in addressing global challenges like poverty, health problems, climate change, etc. It can help in pressing hot issues for providing more coverage to every nook and corner leading to more impactful research (Sianes et al., 2022). Besides

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this, studies linked to SDGs can help in recognizing the interrelationship between different research realms and objectifying the needs of a particular study to give a hands-on impact on real ground. It is also an undeniable fact that the association of research with SDGs not only enhances its influence in shaping a sustainable agenda but also boosts its citation count and global visibility (Bautista-Puig et al., 2021). In addition to these, our findings conclude about the comparative importance of SDG06 (Clean Water and Sanitation) in the sustainable development of every region. Therefore, it is crucial to recognize these findings and proper channelization of small intermittent steps to achieve the bigger accomplishments of a sustainable future. Forthcoming research can address the shortcomings of this study with the use of more sophisticated analytical software like CiteSpace or Bibliometrix package for R Programming to explore more parameters and give a holistic approach to the analysis (Xiong et al., 2020; Gyanendra et al., 2022). The research can be performed with a bigger data set from documents indexed in Scopus and the social media readership can be analysed to track the visibility of the documents as done in Basumatary et al. (2022).

Conclusion

Eutrophication and its associated problems is a research area which has been going on for many decades. Yet, the never-ending and varied problems caused by the non-point sources of its pollutants are complicated and intricate. Scientists and researchers all over the world should work in cooperation, sharing the resources and intellectual strength to develop an environmentally friendly, cheaper, and efficient mode of wastewater treatment. Phytoremediation, Bioremediation, Constructed-Wetlands, Nanotechnology, Machine learning, Hydrological Modelling, Genetic Engineering, etc. are the realms which the new research areas should focus on. The suitability of the Constructed-Wetlands in India should be considered for its efficient and low-cost technology. The vague nature of non-point sources of pollutants can be tackled with views from socio-economic angle besides the technological solutions. There is also the need to focus the energy on favorable funding and financial environment so that the researchers can concentrate their time and energy on novel ideas and productive research activities. The intellectuals, legislators and environmental agencies should work on bringing up a healthy conducive environment which nurtures new ideas and executes them so that the proposed SDGs are met substantially.

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REFERENCES

[1] Ansari, A. A., Gill, S. S. (eds.) (2014): Eutrophication: Causes, consequences and control: Volume 2. – Springer, 262p. doi: 10.1007/978-94-007-7814-6.

[2] Basumatary, B., Manoj, A. K. V., Verma, K. (2022): Global research trends on aquaponics: A systematic review based on computational mapping. – Aquaculture International (0123456789). doi: 10.1007/s10499-022-01018-y.

[3] Bautista-Puig, N., Aleixo, A. M., Leal, S., Azeiteiro, U., Costas, R. (2021): Unveiling the Research Landscape of Sustainable Development Goals and Their Inclusion in Higher Education Institutions and Research Centers: Major Trends in 2000–2017. – Frontiers in Sustainability 2(March): 1-18. doi: 10.3389/frsus.2021.620743.

[4] Calabretta, G., Durisin, B., Ogliengo, M. (2011): Uncovering the Intellectual Structure of Research in Business Ethics: A Journey Through the History, the Classics, and the Pillars of *Journal of Business Ethics*. – Journal of Business Ethics 104: 499-524. doi: 10.1007/s10551-011-0924-8.

[5] Chudnovsky, D., López, A., Rossi, M. A., Ubfal, D. (2008): Money for Science? The Impact of Research Grants on Academic Output. – Fiscal Studies 29(1): 75-87. doi: 10.1111/j.1475-5890.2008.00069.x.

[6] Donthu, N., Kumar, S., Mukherjee, D., Pandey, N., Lim, W. M. (2021): How to conduct a bibliometric analysis: An overview and guidelines. – Journal of Business Research 133: 285-296. doi: 10.1016/j.jbusres.2021.04.070.

[7] Dua, J., Singh, V. K., Lathabai, H. H. (2023): Measuring and characterizing international collaboration patterns in Indian scientific research. – Scientometrics 128: 5081-5116. Springer International Publishing. doi: 10.1007/s11192-023-04794-3.

[8] Elser, J. J., Bracken, M. E. S., Cleland, E. E., Gruner, D. S., Harpole, W. S., Hillebrand, H., Ngai, J. T., Seabloom, E. W., Shurin, J. B., Smith, J. E. (2007): Global analysis of nitrogen and phosphorus limitation of primary producers in freshwater, marine and terrestrial ecosystems. – Ecology Letters 10(12): 1135-1142. doi: 10.1111/j.1461-0248.2007.01113.x.

[9] Gao, W., Chen, Y., Liu, Y., Guo, H.-C. (2015): Scientometric analysis of phosphorus research in eutrophic lakes. – Scientometrics 102(3): 1951-1964. doi: 10.1007/s11192-014-1500-7.

[10] Ge, Y., Liu, X., Chen, L., Zhang, G., Wu, Y., Yang, X., Yang, J. (2023): Attribution of lake eutrophication risk to anthropogenic forcing adjacent to the agriculture areas: a case study of Chagan Lake. – Environmental Science and Pollution Research 30(52): 112159-112172. doi: 10.1007/s11356-023-30110-w.

[11] Gyanendra, Y., Yumnam, G., Alam, W., Ch. Singh, I. (2022): A bibliometric analysis and assessment of scientific studies trend on groundwater research in India during 1989–2020. – Arabian Journal of Geosciences 15(16). doi: 10.1007/s12517-022-10707-0.

[12] Harper, D. (1992): Eutrophication of freshwaters: principles, problems and restoration. – Springer, 327p. 10.1016/0169-5347(92)90240-c.

[13] Haunschild, R., Bornmann, L., Marx, W. (2016): Climate change research in view of bibliometrics. – PLoS ONE 11(7): e0160393. doi: 10.1371/journal.pone.0160393.

[14] Herrera-Navarrete, R., Colín-Cruz, A., Arellano-Wences, H. J., Sampedro-Rosas, M. L., Rosas-Acevedo, J. L., Rodríguez-Herrera, A. L. (2022): Municipal Wastewater Treatment Plants: Gap, Challenges, and Opportunities in Environmental Management. – Environmental Management 69(1): 75-88. doi: 10.1007/s00267-021-01562-y.

[15] Hietala, R., Virkkunen, H., Salminen, J., Ekholm, P., Riihimäki, J., Laine, P., Kirkkala, T. (2024): Assessment of agricultural water protection strategies at a catchment scale: case of Finland. – Regional Environmental Change 24(1). doi: 10.1007/s10113-023-02154-8.

[16] Imani,S., Niksokhan, M. H., Jamshidi, S., Abbaspour, K. C. (2017): Discharge permit market and farm management nexus: an approach for eutrophication control in small basins

with low-income farmers. – Environmental Monitoring and Assessment 189(7). doi: 10.1007/s10661-017-6066-4.

[17] Jaramillo, A. M., Williams, H. T. P., Perra, N., Menezes, R. (2023): The structure of segregation in co-authorship networks and its impact on scientific production. – EPJ Data Science 12: 47. doi: 10.1140/epjds/s13688-023-00411-8.

[18] Kamilya, T., Gautam, R. K., Muthukumaran, S., Navaratna, D., Mondal, S. (2022): Technical advances on current research trends and explore the future scope on nutrient recovery from waste-streams: a review and bibliometric analysis from 2000 to 2020. – Environmental Science and Pollution Research 29(33): 49632-49650. doi: 10.1007/s11356-022-20895-7.

[19] Khan, M. N., Mohammad, F. (2014): Eutrophication: Challenges and Solutions. – In Ansari, A., Gill, S. (eds.) Eutrophication: Causes, Consequences and Control. Dordrecht: Springer Netherlands. doi: 10.1007/978-94-007-7814-6_1.

[20] Kim, M. C., Zhu, Y. (2018): Scientometrics of Scientometrics: Mapping Historical Footprint and Emerging Technologies in Scientometrics. – Scientometrics. doi: 10.5772/intechopen.77951.

[21] Kumar, S., Sangwan, V., Kumar, M., Deswal, S. (2023): A survey on constructed wetland publications in the past three decades', Environmental Monitoring and Assessment. – Springer International Publishing. doi: 10.1007/s10661-023-11516-y.

[22] Lathabai, H. H., Nandy, A., Singh, V. K. (2022): Institutional collaboration recommendation: An expertise-based framework using NLP and network analysis. – Expert Systems with Applications 209: 118317. doi: 10.1016/j.eswa.2022.118317.

[23] Li, S., Zhuang, Y., Zhang, L., Du, Y., Liu, H. (2014): Worldwide performance and trends in nonpoint source pollution modeling research from 1994 to 2013: A review based on bibliometrics. – Journal of Soil and Water Conservation 69(4): 121-126. doi: 10.2489/jswc.69.4.121A.

[24] Li, M., Dong, J., Zhang, Y., Yang, H., Van Zwieten, L., Lu, H., Alshameri, A., Zhan, Z., Chen, X., Jiang, X., Xu, W., Bao, Y., Wang, H. (2021): A critical review of methods for analyzing freshwater eutrophication. – Water (Switzerland) 13(2): 1-20. doi: 10.3390/w13020225.

[25] Mendes, F., Cristiane, B., Gattaz, C. (2018): 60 years : review and future trends in the field of business through the citations and co-citations analysis. – Scientometrics 115(3): 1329-1363. doi: 10.1007/s11192-018-2709-7.

[26] Nazari-Sharabian, M., Ahmad, S., Moses, K. (2018): Climate change and groundwater : a short review. – Engineering, Technology and Applied Science Research 8(6): 3668-3672. Available at: https://digitalscholarship.unlv.edu/fac_articles/562.

[27] Officer, C., Smayda, T., Mann, R. (1982): Benthic Filter Feeding: A Natural Eutrophication Control. – Marine Ecology Progress Series 9: 203-210. doi: 10.3354/meps009203.

[28] Pan, S., Bian, Z., Tia, H., Yao, Y., Najjar, R. G., Friedrichs, M. A. M., Hofmann, E. E., Xu, R., Zhang, B. (2021): Impacts of Multiple Environmental Changes on Long-Term Nitrogen Loading From the Chesapeake Bay Watershed. – Journal of Geophysical Research: Biogeosciences 126(5). doi: 10.1029/2020JG005826.

[29] Pritchard, A. (1969): Statistical Bibliography or Bibliometrics. – Journal of Documentation 25(4): 348-349.

[30] Rai, P. K. (2008): Heavy metal pollution in aquatic ecosystems and its phytoremediation using wetland plants: An ecosustainable approach. – International Journal of Phytoremediation 10(2): 133-160. doi: 10.1080/15226510801913918.

[31] Scheer, A., Kruppke, H., Heib, R. (2001): Multiple Criteria Decision Making in the New Millennium. – Springer-Verlag Berlin Heidelberg GmbH. doi: 10.1007/978-3-642-56680-6.

[32] Schindler, D. W. (1974): Eutrophication and Recovery in Experimental Lakes - Implications for Lake Management. – Science 184(4139): 897-899.

[33] Schindler, D. W. (2006): Recent advances in the understanding and management of eutrophication. – Limnology and Oceanography 51: 356-363. doi: 10.4319/lo.2006.51.1_part_2.0356.

[34] Sekine, M., Ukita, M., Nakanishi, H. (1991): Systematic Pollutegraph Simulation for Real Scale River Basin. – Water Science and Technology 23(1-3): 141-150. doi: 10.2166/wst.1991.0410.

[35] Sianes, A., Vega-Muñoz, A., Tirado-Valencia, P., Montes, A. A. (2022): Impact of the Sustainable Development Goals on the academic research agenda. A scientometric analysis. – PLoS ONE 17(3): 1-23. doi: 10.1371/journal.pone.0265409.

[36] Smith, V. H., Schindler, D. W. (2009): Eutrophication science: where do we go from here? – Trends in Ecology and Evolution 24(4): 201-207. doi: 10.1016/j.tree.2008.11.009.

[37] Tian, H., Xu, X., Zhang, C., Ren, W., Chen, G., Liu, M., Lu, D., Pan, S. (2009): Forecasting and Assessing the Large-Scale and Long-Term Impacts of Global Environmental Change on Terrestrial Ecosystems in the United States and China. – In: Real World Ecology. New York, NY: Springer New York, pp. 235-266. doi: 10.1007/978-0-387-77942-3_9.

[38] Ubfal, D., Maffioli, A. (2011): The impact of funding on research collaboration: Evidence from a developing country. – Research Policy 40(9): 1269-1279. doi: 10.1016/j.respol.2011.05.023.

[39] Uddin, S., Hossain, L., Abbasi, A., Rasmussen, K. (2012): Trend and efficiency analysis of co-authorship network. – Scientometrics 90(2): 687-699. doi: 10.1007/s11192-011-0511-x.

[40] Vinçon-Leite, B., Casenave, C. (2019): Modelling eutrophication in lake ecosystems: A review. – Science of the Total Environment 651: 2985-3001. doi: 10.1016/j.scitotenv.2018.09.320.

[41] Vymazal, J. (2011): Constructed Wetlands for Wastewater Treatment : Five Decades of Experience. – Environ. Sci. Technol. 45(1): 61-69.

[42] Wang, L., Zhaob, X., Gaoa, J., Butterly, C. R., Chena, Q., Liua, M., Yanga, Y., Xia, Y., Xiaoa, X. (2019): Effects of fertilizer types on nitrogen and phosphorous loss from rice-wheat rotation system in the Taihu Lake region of China. – Agriculture, Ecosystems and Environment 285: 106605. doi: 10.1016/j.agee.2019.106605.

[43] Web of Science. – Available at: https://www.webofscience.com/wos/woscc/basic-search.

[44] Xia, Y., Zhang, M., Tsang, D. C. W., Geng, N., Lu, D., Zhu, L., Igalavithana, A. D., Dissanayake, P. D., Rinklebe, J., Yang, X., Ok, Y. S. (2020): Recent advances in control technologies for non-point source pollution with nitrogen and phosphorous from agricultural runoff: current practices and future prospects. – Applied Biological Chemistry 63: 8. doi: 10.1186/s13765-020-0493-6.

[45] Xiang, C., Wang, Y., Liu, H. (2017): A scientometrics review on nonpoint source pollution research. – Ecological Engineering 99: 400-408. doi: 10.1016/j.ecoleng.2016.11.028.

[46] Xiong, H., Zhao, Z. (2020): The correlation between haze and economic growth: bibliometric analysis based on WOS Database. – Applied Ecology and Environmental Research 18(1): 59-75. doi: 10.15666/aeer/1801_059075.

[47] Yang, X. E., Wu, X., Hao, H-L., He, Z-L. (2008): Mechanisms and assessment of water eutrophication. – Journal of Zhejiang University: Science B 9(3): 197-209. doi: 10.1631/jzus.B0710626.

[48] Yao, X., Zhang, Y., Zhang, L., Zhou, Y. (2018): A bibliometric review of nitrogen research in eutrophic lakes and reservoirs. – Journal of Environmental Sciences (China) 66: 274-285. doi: 10.1016/j.jes.2016.10.022.

[49] Zhuang, Y., Thuminh, N., Niu, B., Shao, E., Song, H. (2012): Research Trends in Non Point Source during 1975-2010. – Physics Procedia 33: 138-143. doi: 10.1016/j.phpro.2012.05.041.