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OVERVIEW

A bibliometric study on the use of diatoms in water quality monitoring and bioassessment in Africa across 10-year (2012–2022) period

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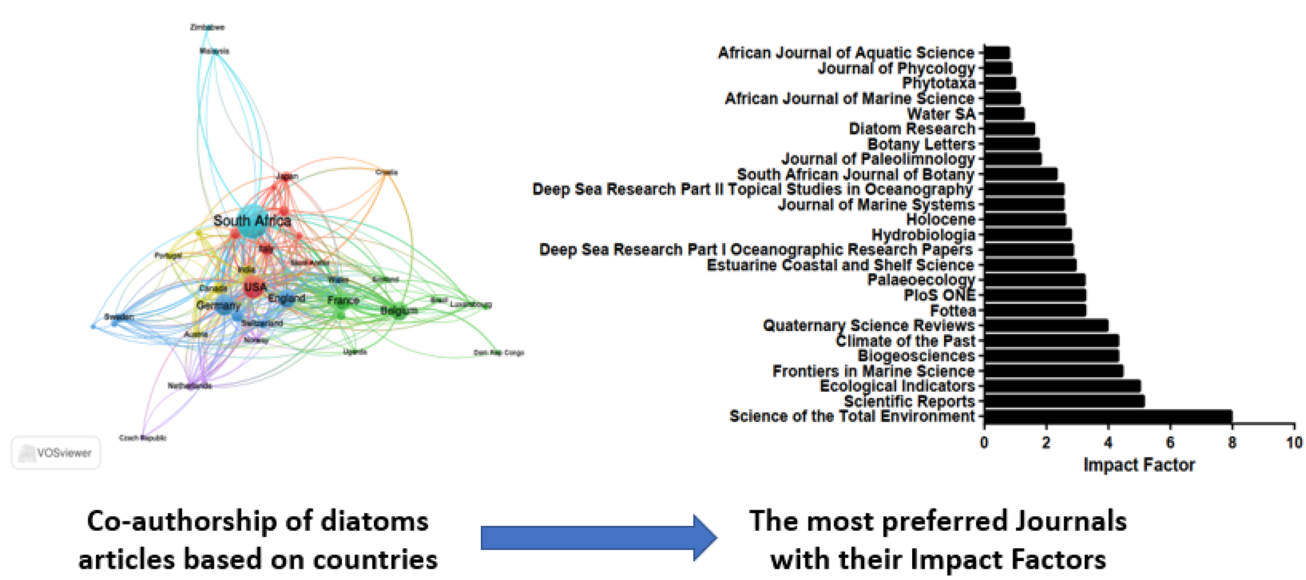
Abstract

Living organisms are used in water quality evaluation, thus reflecting the constantly changing physical and chemical characteristics of aquatic ecosystems. Diatoms are among the aquatic organisms used in water quality monitoring of both lentic and lotic ecosystems. The objectives of our present study were to summarize the topics in diatoms for water quality evaluation, and identify the past trends as well as the future directions through the analyses of trends in diatoms bioassessment topics in Africa. We retrieved diatoms distribution data from Web of Science (WoS) database using the following keywords "Diatoms for water quality monitoring in Africa", and "Diatoms for bioassessment in Africa". We used VOS viewer software (version 1.16.15) in the construction of knowledge map of application diatoms in monitoring and bioassessment. A total of 481 documents on diatom in water quality monitoring and bioassessment were found. A subsequent thresholding of keywords centered on 15 times occurrence yielded 37 keywords. Diatom indicators were related to diversity, benthic diatoms, communities, community structure, assemblages, land-use, and water quality as clustered by VOS viewer software. Regionally, South Africa is one of the top most developed country in Africa, and this has been attributted to greater infrastructural, human resource, and financial capacity to carry out research that led to substantial collaborations both locally and globally. Institutionally, the connection between University of Cape Town and Bayworld Centre for Research and Education in South Africa was strongest probably due to their better infrastructural capacity in diatoms research. Therefore, the study provided insights that are likely to contribute to the future development of water quality monitoring framework using diatoms in Africa, thereby enhancing global environmental sustainability.

Graphical abstract



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Keywords Benthic diatoms · Environmental sustainability · Indicators · Water quality assessment

Introduction

Physicochemical and biological evaluation have been applied for decades for the detection of anthropogenic activities on aquatic ecosystems (Salmaso et al. 2019). However, physical monitoring is considered inaccurate and incomplete since it reflects the water quality condition only at the short period of time as compared to biological assessment that is perceived as more accurate and holistic because it reflects the water quality condition for an extended period of time (Falasco et al. 2021; Ochieng et al. 2022; Tan et al. 2021; Tornés et al. 2022, 2021). Among the organisms used for biological evaluation include diatoms (Falasco et al. 2021; Mbao et al. 2020). The wide use of diatoms in bioassessment is attributed to the fact they are found in almost all aquatic environments and they have various life strategies adapting to multiple aquatic habitats (Mbao et al. 2020). Further, diatoms live on different substrates such as mud, sand, stones, rocks, plants, and animals (Vasselon et al. 2017; Zimmermann et al. 2015). Compared to benthic macroinvertebrates and fishes, they have a shorter generation time and are more sensitive to nutrients (Cilleros et al. 2019; Zimmermann et al. 2015). Thus, they are good indicators providing early-warning signals of water quality degradation resulting from increased nutrient concentrations (Saxena et al. 2021). In addition, fossil records of diatoms in sediments are useful for the reconstruction of paleoenvironments since their siliceous frustules can withstand natural decomposition, thus remaining intact for a very long period (Hamilton et al. 2021; Keck et al. 2018).

In Africa, biological assessment of water quality using diatoms is still at its nascent stage as compared to fast developing countries like China, and the developed continent of Europe and North America (Mbao et al. 2020). In the USA and Europe for instance, various environmental statutory legislation requirements such as the Environmental Monitoring and Assessment Program for Surface Waters EPA/620/R-94/004F (EMAP-SW) (Dixit and Smol 1994), and Water Framework Directive 2000/60/EC (Kelly et al. 2008, 2012), respectively, were developed to safeguard the aquatic environment by evaluating the trophic and biotic integrity conditions, using organisms including diatoms as bioindicators (Kelly et al. 2008). In Africa, South Africa is leading the way in monitoring and protecting aquatic ecosystems using benthic diatoms (Taylor et al. 2014). Additionally, Kenya (Triest et al. 2012) has diatom biomonitoring programs, with countries such as Zimbabwe (Bere et al. 2014) and Zambia (Lang et al. 2012) beginning to embrace diatom-based indices for water quality monitoring. However, despite the relative cost-effectiveness of using diatoms in water quality monitoring, this approach has largely been ignored in Africa (Cocquyt et al. 2013).

Despite the growing concerns and publications about water quality degradation, no study has comprehensively addressed the analysis of the current development trends in the water quality evaluation using diatoms domain in Africa. To bridge this gap in relevant publications about water quality monitoring using diatoms in Africa, we undertook a bibliometric analysis of the current research status using VOS viewer software. As a crucial bibliometric software, VOS viewer has been used widely in the identification of vital development trends of research domain globally (Kim and Chen 2015; Yu et al. 2017). Our study presents a bibliometric review of the current research trends and hotspots in the use of diatoms in water quality monitoring in Africa. Among the parameters analyzed were quantitative description of research and publications trends, and keywords depicting research hotspots. Further, we carried out an in-depth analysis of the publications selected and discussed crucial insights on the distribution patterns of diatoms, comprehensive diatom studies, institutions involved in diatoms collaborative research, and major diatom taxa recorded in Africa. Our main objectives were (1) to summarize the topics in diatom water quality assessment; (2) to identify past trends as well as the future directions through trend analyses in diatom bioassessment topics; and (3) to determine regional and institutional trend analyses in diatom evaluation topics in Africa. Therefore, this study will contribute to the development of the water quality monitoring framework using diatoms in Africa, thus improving global environmental sustainability. A future perspective was highlighted and recommendations about the current challenges on diatoms studies in Africa outlined.

Materials and methods

Data sources

We retrieved diatoms distribution data from Web of Science (WoS) database using the following keywords “Diatoms for water quality monitoring in Africa”, and “Diatoms for bioassessment in Africa”. In the literature search study, we considered the Science Citation Index Expanded (SCI-EXPANDED) from 2012 to 2022. The inclusion threshold involved studies that reported the use of diatoms in water quality monitoring, and diatom indices in bioassessment. Our search was restricted on language, field of study, and document-type. English research articles in the fields of Water resources, Ecology, and Environmental sciences were exclusively included since they met our selection criteria. We conducted a preliminary selection criterion on the basis of the articles' titles and abstracts, with further screening of the contents of the identified articles. The full inventory of the article journals that included name of the publishing article, publication date, title, authors, affiliation, and abstract were downloaded after the search and used as primary source of data for this review. The selection of journal for this analysis was mainly based on their dominance and the fact that they had undergone peer-review process, hence considered as having reliable information due to rigorous scrutiny of information and data, a logic applied by many bibliometric studies (Cardoso et al. 2020; Sweileh 2020). We also downloaded from the database, a journal citation report to relate the searched article to the journals of publication, scientific disciplines and their affiliated citation. Additionally, we related the highly cited journals to their impact factors. From our search results, 481 articles met the selection criterion and upon further screening, only 453 articles met the inclusion threshold.

Data analysis

We employed various methods to analyze the data retrieved from the WoS database to describe trends in literature, quantitative relationships, and key information on the use of diatoms in water quality monitoring and diatoms in bioassement in Africa. We assayed the interconnection between impact factor (I.F) of the highly cited journals and the H-index. I.F measures the frequency with which the average article has been cited in a journal in a particular year, while H-index evaluates quantity with quality by comparing citations to publications (Grech and Rizk 2018). Both metrics are standard measures of evaluating the quality and academic performance for both publishers and authors (Grech and Rizk 2018).

We used VOS viewer software (version 1.16.15) in the construction of knowledge map of application diatoms in monitoring and bioassessment, since VOS viewer is a bibliometric tool primarily used in analyzing and visualizing scientific literature as well as promoting knowledge interactions and dissemination among different fields (Van Eck and Waltman 2010). The VOS viewer software performs interrelations of various facets of the articles using curved lines and circles. The circles denote particular components whose relationship is being determined, while the lattices designates the robustness of interrelations of the research facets. Subsequently, highly ranked items are denoted by thicker curved lines and larger circles and vice versa. Additionally, the colors of the lines and circles are different, designating different clusters built on similar characteristics such as common institutional collaborations, similar research discipline or co-authorship among others. Further, the thicker curved lines are indicative of robust interrelations of the components and subject in question. The partnership between and among institutions along with the authors were delineated by authors affiliation addresses' to determine their concurrence (Van Haselen 2007).

Countries and institutions actively contributing to research involving diatoms in water quality monitoring and bioassessment in Africa were assayed using VOS viewer program mapping to relate the articles and the affiliated authors. We limited our search on document types to research articles only because they presented empirical findings. Analysis of authors' keywords and keywords from the database focusing on the rank and conccurrence was done. Moreover, Hirsch (h) index was applied as a representative indicator of the scientific impact that resulted from the articles searched (Bornmann and Daniel 2009; Hirsch 2007). Further, quantitative and qualitative indicators of all the analyses included the growth trends of publications and citation counts that were illustrated in graphs plotted using GraphPad Prism version 6.0.

Results

A total of 481 documents on diatoms in water quality monitoring and bioassessment were found by adopting the aforementioned research query between the January 2012 and February 2022. These research articles were published in 117 English journals. A slight growth in publications was observed in the evaluated years as shown in Fig. 1. Articles record count, impact factor, H-index and impact factor rank of the top 25 highly cited journals are indicated (Table 1). These 25 journals were found to have published ≥ 5 articles based on the topic searched and include about 50% of the total number of published papers found in the WoS search. Quaternary Science Reviews journal published the highest number of articles constituting 4.6% of the total record count and 7th according to the impact factor ranking, whereas Diatom Research and Phytotaxa had the 2nd highest number of articles, making up 3.3% of the total searched documents each. However, compared to Diatom Research, Phytotaxa had lower IF value.

The interconnection between H-index and impact factor showed no clear trend (Fig. 2). The bibliographic coupling of journals identified by the use of VOS viewer program at a threshold set at thirty citations per article revealed that only 35 out of 453 met these conditions, and these included Quaternary Science Reviews, Ecological Indicators, Diatom Research, Phytotaxa and African Journal of Marine Sciences

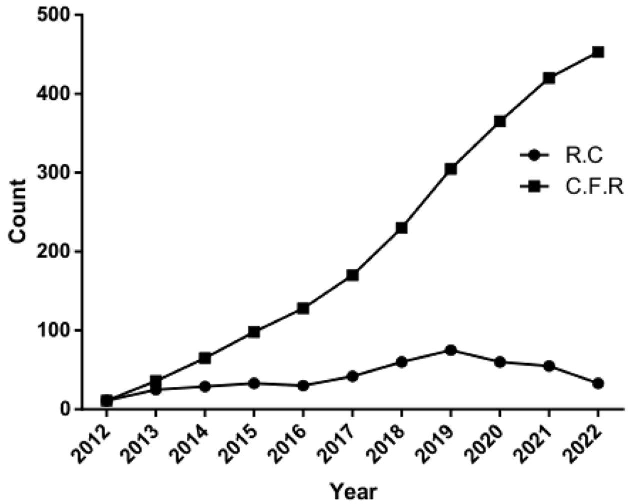

Fig. 1 Publication trend represented as record count (R.C) and cumulative frequency of records (C.F.R) of the documents searched during the 2012 to 2022 period

among others (Fig. 3). A total of 86 nations were identified to be involved in research on diatoms in water quality monitoring in Africa, with South Africa taking the lead with 234 (51.7%) publications out of 453 (Table 2), a trend that was evidently reflected in the bibliographic coupling of countries where South Africa remained dominant (Fig. 4).

The 20 most active research institutions are indicated in Table 3, and National Research Foundation of South Africa topped the list with 15% of the total records count. The VOS viewer program mapped the co-authorship of institutions and established the collaborative efforts. The threshold for the software was set at a minimum of 5 documents and 5 citations per organization where 68 of all institutions met this standard. University of Cape Town and North West University South Africa were among the best collaborators (Fig. 5).

The major thematic areas are shown in Table 4, with publications in Marine and Freshwater Biology dominating at 26.9%. The VOS viewer program assayed the co-occurrence of keywords, identifying a total of 3071 keywords. A subsequent thresholding of keywords centered on 15 times occurrence yielded 37 keywords as mapped out in Fig. 6. The broader theme of diatom evolution is related

Table 1 Highly cited journals on diatoms in water quality monitoring in Africa ordered by decreasing impact factor

Rank	Publication titles	Count (%)	Impact factor	Impact factor rank	H-index
1	Science of the Total Environment	12 (2.6)	7.96	1.80	244
2	Scientific Reports	7 (1.5)	5.13	1.24	213
3	Ecological Indicators	9 (2.0)	5.00	1.32	127
4	Frontiers in Marine Science	8 (1.8)	4.44	1.56	49
5	Biogeosciences	12 (2.6)	4.30	1.74	127
6	Climate of the Past	7 (1.5)	4.30	2.03	76
7	Quaternary Science Reviews	21(4.6)	3.96	1.88	182
8	Fottea	9 (2.0)	3.24	0.78	25
9	PloS ONE	7 (1.5)	3.24	0.99	332
10	Palaeoecology	12 (2.6)	3.22	1.30	154
11	Estuarine Coastal and Shelf Science	11 (2.4)	2.93	0.85	134
12	Deep sea Research Part I Oceanographic research Papers	7 (1.5)	2.85	1.13	122
13	Hydrobiologia	6(1.3)	2.78	0.84	141
14	Holocene	7 (1.5)	2.59	1.01	117
15	Journal of Marine Systems	6 (1.3)	2.54	0.83	105
16	Deep Sea Research Part II Topical Studies in Oceanography	7 (1.5)	2.54	1.17	140
17	South African Journal of Botany	6 (1.3)	2.32	0.50	59
18	Journal of Paleolimnology	9 (2.0)	1.81	0.66	84
19	Botany Letters	5 (1.1)	1.74	0.40	19
20	Diatom Research	15 (3.3)	1.59	0.61	35
21	Water SA	9 (2.0)	1.25	0.39	59
22	African Journal of Marine Science	11 (2.4)	1.13	0.36	50
23	Phytotaxa	15 (3.3)	0.98	1.17	36
24	Journal of Phycology	6 (1.3)	0.85	2.92	127
25	African Journal of Aquatic Science	14 (3.1)	0.78	0.28	28

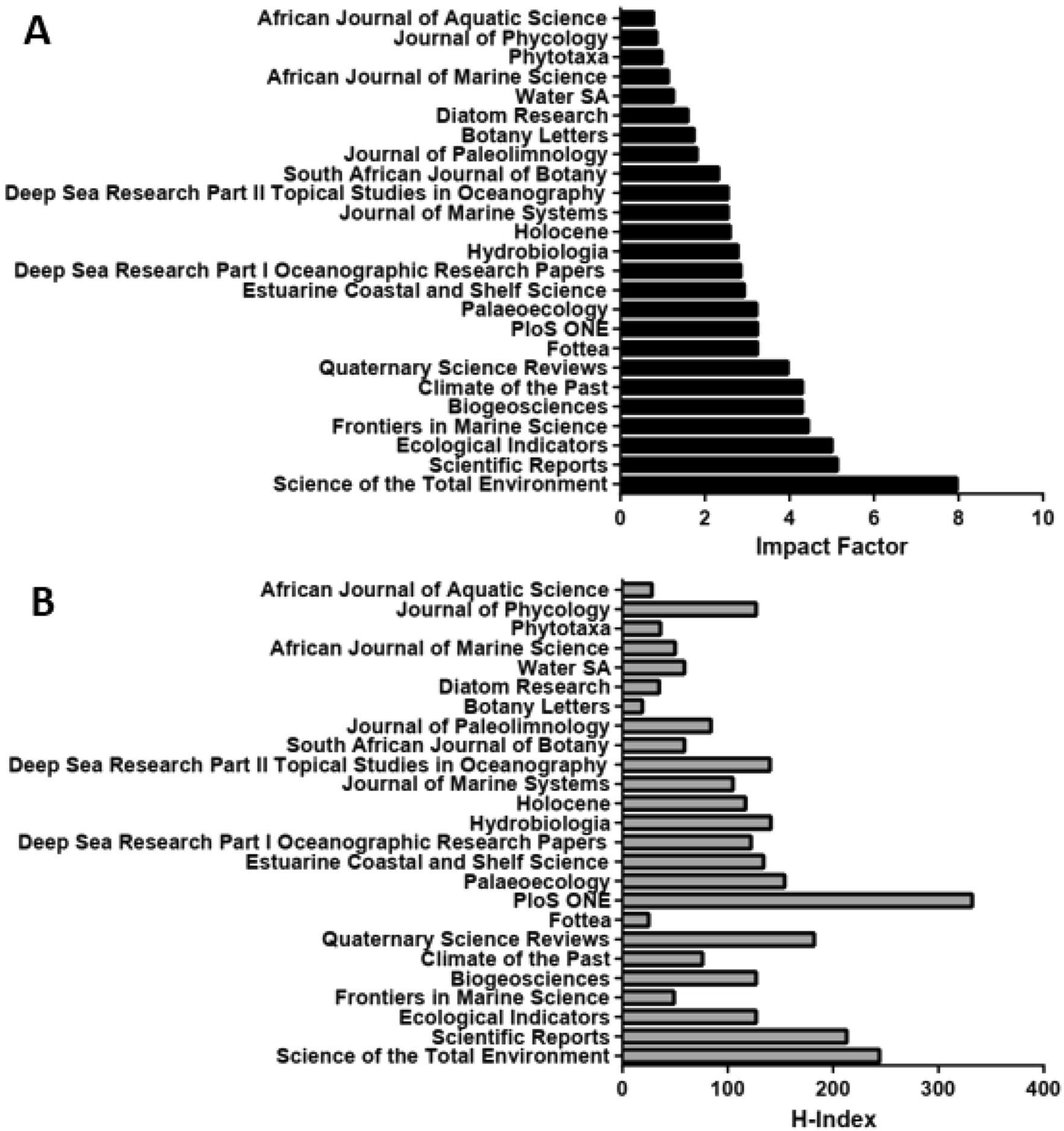

Fig. 2 The variation of the Impact factor (**A**) and H-index (**B**) of the 25 most cited journals of the searched query between January 2012 and February 2022

to diatom records, variability, sediments, climate, climate-change, Holocene, late Pleistocene, organic matter, and diatom dynamics. The other theme on diatom taxonomy is related to new species, morphology, Bacillariophyta, freshwater, and lake, whereas theme of diatom indicators is related to diversity, benthic diatoms, communities, community structure, assemblages, land-use, and water quality. A total of 5767 authors were identified from the search query and when the limit of co-citation, i.e., the frequency with which any two documents are cited together by other documents, was adjusted to a minimum of 70 citations per pair of authors, 73 authors met this threshold with the resulting mapping of their interrelationship shown in Fig. 7.

Discussion

The analysis of document-type and language

This paper constitutes the first bibliometric study on the use of diatoms as bioindicators in Africa. African research

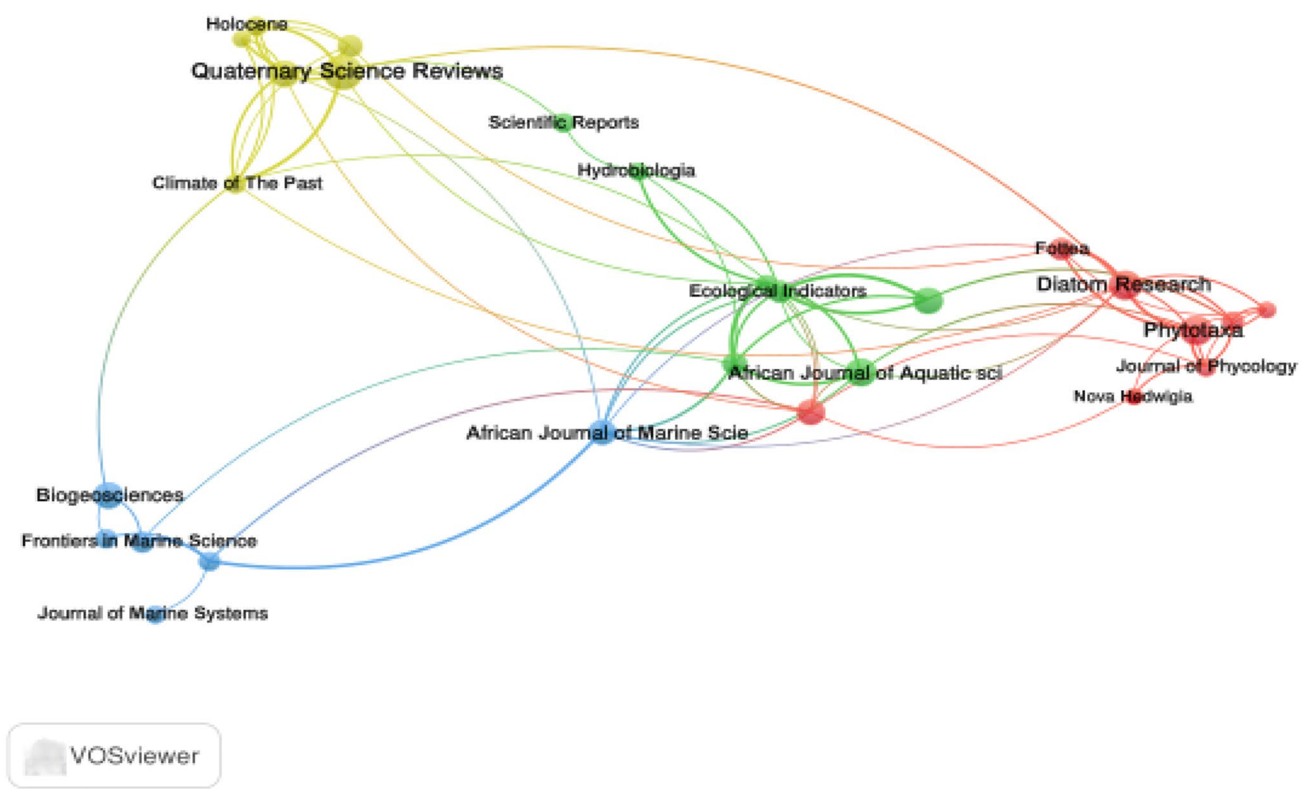

Fig. 3 Citation analysis sources: map of diatoms in water quality monitoring topics based on keywords (author keywords and keywords plus) set at a threshold of 30 citations per article between January 2012 and February 2022, constructed using VOSviewer software. The size of each circle represents the frequency of that keyword, and the color of the circle represents clustering determined with VOSviewer

topics were objectively summarized and diatom research trends were identified. Our study showed that publications of documents largely related to diatoms were mainly in North America and Europe. All the articles searched were written in English since it is considered as lingua franca of scientific studies and common mode of communication world-wide (Károly et al. 2020). Bibliometric analysis of African countries revealed that South Africa has contributed far more than any other country in Africa to diatoms research. Among the possible reasons is that English is the official language in South Africa. This is because the non-English speaking nations are disadvantaged when it comes to writing as well as publishing articles in English (Károly et al. 2020). Additionally, the level of development of South Africa is relatively high in comparison to other countries on the continent. In the relatively undeveloped nations of Africa, the number of researchers is lower, coupled with insufficient government support in terms of research funds. In South Africa, the use of diatoms as biological indicators to monitor environmental health is on the rise, and publications related to diatoms are numerous (Table 4).

Journal analysis

Quaternary Science Reviews journal publishes research on environmental issues related to geomorphology, archaeology, palaeobotany, palaeoclimatology, geology, geography, soil science, and a wide-range of applicable dating methods, with diatom studies being well-known as a dating method for decades (Swann and Leng 2009). Additionally, Phytotaxa journal publishes research on any aspect of botany, with emphasis on floras, monographs and new species, including those of diatoms (Joh 2021). These two journals displayed largest circles coupled with thickest lines of connection in comparison with the other journals analyzed. This observation generally ascertained high article output and citations that contributed to the high total linkage strength when compared to the rest of the journals. Relatively, other journals considered to be top most active publishers had remarkably stronger linkage strength, a fact associated to high citations of their publications. Journals clustered together in the bibliographic network, having similar colors illustrating similarities in their scope of publishing as reported by Gautam (2019) in his study of applications of scientometrics in analyzing research publications using various classification schemes.

Table 2 Countries/regions that published highly on the search query ordered by decreasing record count (%)

	Countries/regions	Count (%)	H-index
1	South Africa	234 (51.7)	531
2	USA	97 (21.4)	2577
3	Germany	85 (18.8)	1429
4	Belgium	69 (15.2)	886
5	England	63 (13.9)	1618
6	France	60 (13.2)	1286
7	Italy	32 (7.1)	1135
8	Spain	28 (6.2)	1010
9	Canada	23 (5.1)	1299
10	Peoples R China	23 (5.1)	1010
11	India	20 (4.4)	691
12	Japan	20 (4.4)	1118
13	Poland	19 (4.2)	630
14	Australia	16 (3.5)	1115
15	Sweden	16 (3.5)	974
16	Netherlands	15 (3.3)	1133
17	Switzerland	14 (3.1)	1085
18	Portugal	11 (2.4)	560
19	Tanzania	10 (2.2)	191
20	Wales	10 (2.2)	591
21	Russia	9 (2.0)	652
22	South Korea	9 (2.0)	762
23	Austria	8 (1.8)	740
24	Egypt	7 (1.5)	322
25	Kenya	7 (1.5)	283

Through our present study by analyzing the journals, we revealed that diatoms-based research as bioindicator in assessing environmental conditions is becoming popular in Africa (Cocquyt and Taylor 2016; Van De Vijver et al. 2010). Diatoms have been used to monitor the unprecedented intensive anthropogenic disturbances altering the environmental conditions, resulting to water quality degradation and human-induced climate change that are a great concern to environmentalists and ecologists as revealed by the journals'publications in this study. The use of diatoms as bioindicators in water quality assessment started as early as twentieth century (Wu et al. 2017), triggered by degraded water quality in streams, rivers, reservoirs and lakes among others, caused by human activities such as agriculture and urbanization. Additionally, human-induced climated change caused by global warming has had an enormous impact on these aquatic ecosystems (Peeters et al. 2007), thereby altering the timings of algal blooms and consequently enhancing the proliferation of harmful algal blooms (Kosten et al. 2012), hence leading to a remarkable increase in diatoms research related to climate change over the last decade. Our results also revealed that studies on paleoclimate such as late Pleistocene and Holocene climate in relation to diatoms were being adopted in Africa (Fitchett et al. 2017; Kylander et al. 2021). In paleoclimatic research, scientists use diatoms in reconstructing ancient climate and learning about climate change (Adams et al. 2014). Therefore, diatoms have been considered as more precise in the assessment of the trophic status of water bodies and also reflecting current climatic changes in aquatic ecosystems globally (Kylander et al. 2021).

Regional/country analysis of searched articles

Regionally, South Africa and Egypt were the most active countries in Africa, while globally the USA dominated. South Africa and Egypt are among the top most developed countries in Africa, featuring prominently in aquatic research involing the use of diatoms in bioassessment, while USA is actively promoting network meta-analysis research. The developed countries of Europe, North America, and fast developing nations like China overshadowed the poor developing nations of Africa in all the fields, a trend that has been reported for several decades in previous scientometric research (Nyika et al. 2021). This trend has been attributted to greater infrastructural, human resource, and financial capacity to carry out research that led to substantial collaborations both locally and globally (Pesta et al. 2018; Wang et al. 2018). With the increase in the development of science and technology, research on diatoms are increasingly becoming comprehensive, resulting to a decrease in individual basic studies globally and in Africa, moreso South Africa (Taylor et al. 2010). To start with, studies on the culture and growth of diatoms, were extremely popular in the nineteenth century and have been considered as the foundation of further research on diatoms such as biofuel production, toxicological tests, and species competition studies in batch cultures among others. Second, the behavioral, morphological, and physiological traits of diatoms such as size, diatom motility, diel cycle, inorganic carbon assimilation, and pigmentation have been used as the foundation of research in topics like diatoms' functional diversity, that involves studies of diatoms traits (Cocquyt and Ryken 2017; Cocquyt et al. 2017). Third, research on diatom community structure is increasingly expanding at spatio-temporal scale (Dong et al. 2012; Kissling et al. 2018; Rantala et al. 2017), with many freshwater ecologists acknowledging that diatoms are most likely to be both structured spatially and temporally (Potapova and Charles 2002). Additionally, studies on diatoms globally and moreso in Africa, and specifically in South Africa, are focusing on the multiple facets' aspect of biodiversity like functional diversity, genetic diversity, and taxonomic diversity (Cocquyt et al. 2017; Morin et al. 2012), since researchers have recognized that there is a global trend of declining biodiversity caused by human disturbances

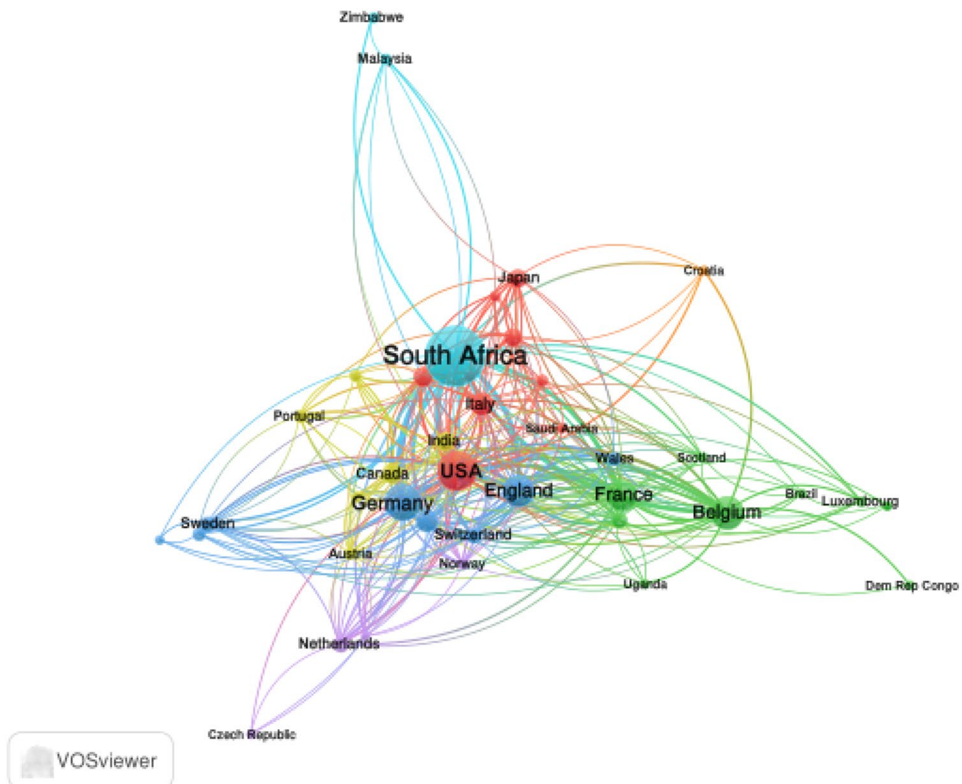

Fig. 4 Co-authorship based on countries: map of diatoms in water quality monitoring topics based on keywords (author keywords and keywords plus) set at a threshold of 30 citations per article between January 2012 and February 2022, constructed using VOSviewer software. The size of each circle represents the frequency of that keyword, and the color of the circle represents clustering determined with VOSviewer

Table 3 The top 20 institutions actively publishing on diatoms in water quality monitoring articles from Africa ordered by decreasing record count (%)

Rank	Institution	Count (%)
1	National Research Foundation South Africa	68 (15.0)
2	University of Cape Town	61 (13.5)
3	North West University South Africa	57 (12.6)
4	South African Institute for Aquatic Biodiversity	56 (12.4)
5	Centre National De La Recherche Scientifique CNRS	46 (10.2)
6	Nelson Mandela University	46 (10.2)
7	Rhodes University	34 (7.5)
8	Institut De Recherche Pour Le Developpement IRD	32 (7.1)
9	Helmholtz Association	28 (6.2)
10	Bot garden Meise	22 (4.9)
11	Council for Scientific Industrial Research CSIR South Africa	22 (4.9)
12	Ghent University	22 (4.9)
13	University of Witwatersrand	19 (4.2)
14	Stellenbosch University	17 (3.8)
15	CNRS National Institute for Earth Sciences Astronomy INSU	16 (3.5)
16	Alfred Wegener Institute Helmholtz Centre for Polar Marine Research	15 (3.3)
17	Natural Environment Research Council	15 (3.3)
18	UK Research Innovation	15 (3.3)
19	University of Antwerp	15 (3.3)
20	South African Environmental Observation Network	14 (3.1)

which are predicted to pose a severe impact on aquatic ecosystems (Sjöqvist and Kremp 2016). Further, with the development of molecular technology and innovation of scanning microscopy, diatom structure (Cilleros et al. 2019; Mortágua et al. 2019) and sequencing of their genes (Pérez-Burillo et al. 2020) is currently widely being applied in the

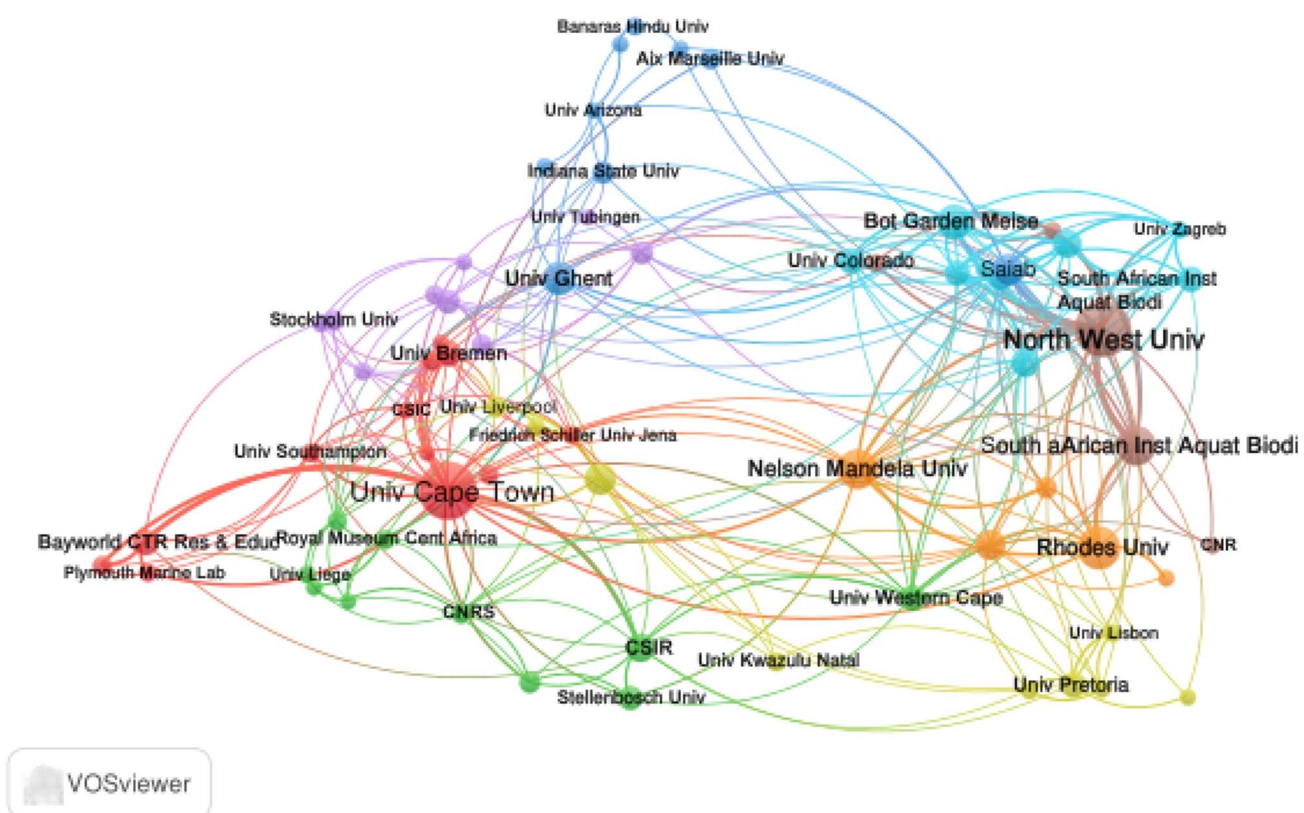

Fig. 5 Co-authorship of institutions: map of diatoms in water quality monitoring topics based on keywords (author keywords and keywords plus) set at a threshold of 5 articles and 5 citations per institution between January 2012 and February 2022, constructed using VOSviewer software. The size of each circle represents the frequency of that keyword, and the color of the circle represents clustering determined with VOSviewer

classification of diatoms contrary to the traditional classification based on morphology as observed under the light microscope. Finally, with the increasing research on diatoms being published, scientists have analyzed, refined and summarized materials and data in the original research papers and added their own perspective to write reviews related to diatoms, hence this review topic also presents an increasing popularity trend overtime, more so in Europe, North America, China and Australia than in Africa with South Africa dominating (De Ridder and Taylor 2020).

Institutional analysis

The WoS revealed the institutions involved in research revolving around the use of diatoms in water quality monitoring or bioassessment in Africa using authors affiliations. In this study, the institutional analysis complemented country analysis, solving the complexities in authors' addresses and avoiding errors during aggregation of the articles. A study by Noyons et al. (2003), documented that address data usage in scientometric analysis remains complex, therefore, main institutions like Research institutes, Companies and Unversities are appropriate. Cardoso et al. (2020), revealed that collaborations among and between institutions is a good approach in creating and disseminating knowledge, as assayed in the present study. Further, Ding et al. (2000) agreed with Cardoso et al. (2020), and outlined that collaborations are considered as concerted scientific efforts aimed at solving challenging global issues. In the present study, the connection between University of Cape Town and Bayworld Centre for Research and Education was strongest followed by the cooperation between North West University and South African Institute of Aquatic Biodiversity based on the thickness of the lines joining them. However, the cooperation among the rest of the institutions was relatively weak as illustrated by the network which was clearly simplistic. Therefore, it can be reasonably inferred that more studies can be published if University of Cape Town and North West University coorperate together in future research, probably due to their better infrastructural capacity in diatoms' research.

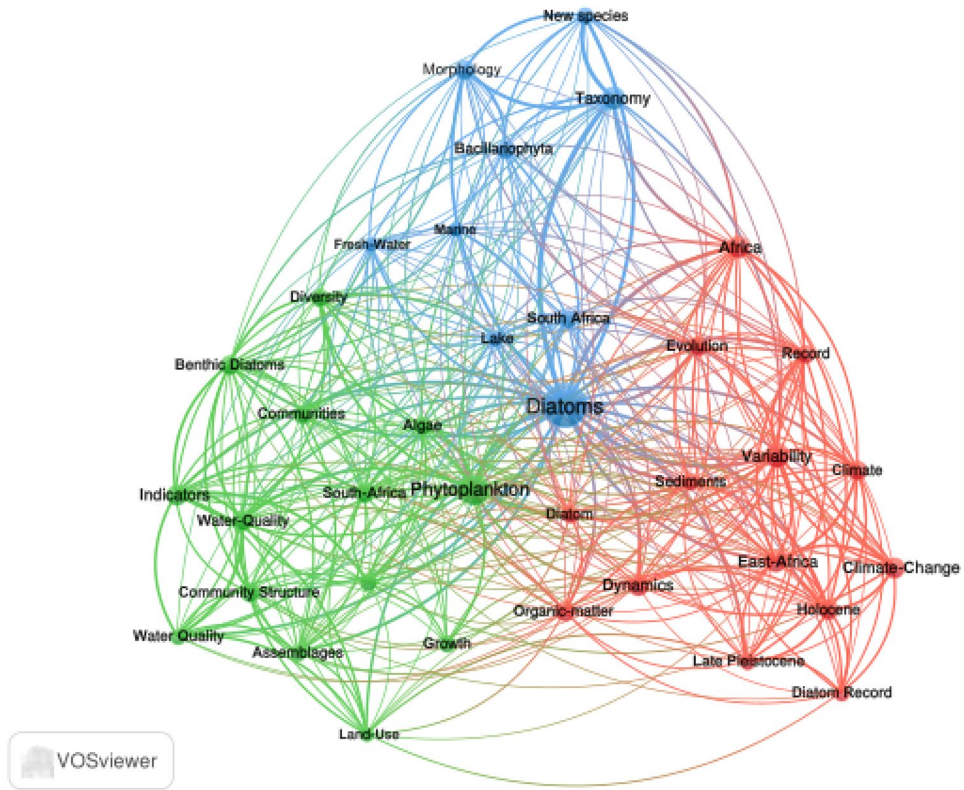

Fig. 6 Concurrences of the keywords on the search query: map of diatoms in water quality monitoring topics based on keywords (author keywords and keywords plus) at a threshold of 15 times occurrence between January 2012 and February 2022, constructed using VOSviewer software. The size of each circle represents the frequency of that keyword, and the color of the circle represents clustering determined with VOSviewer

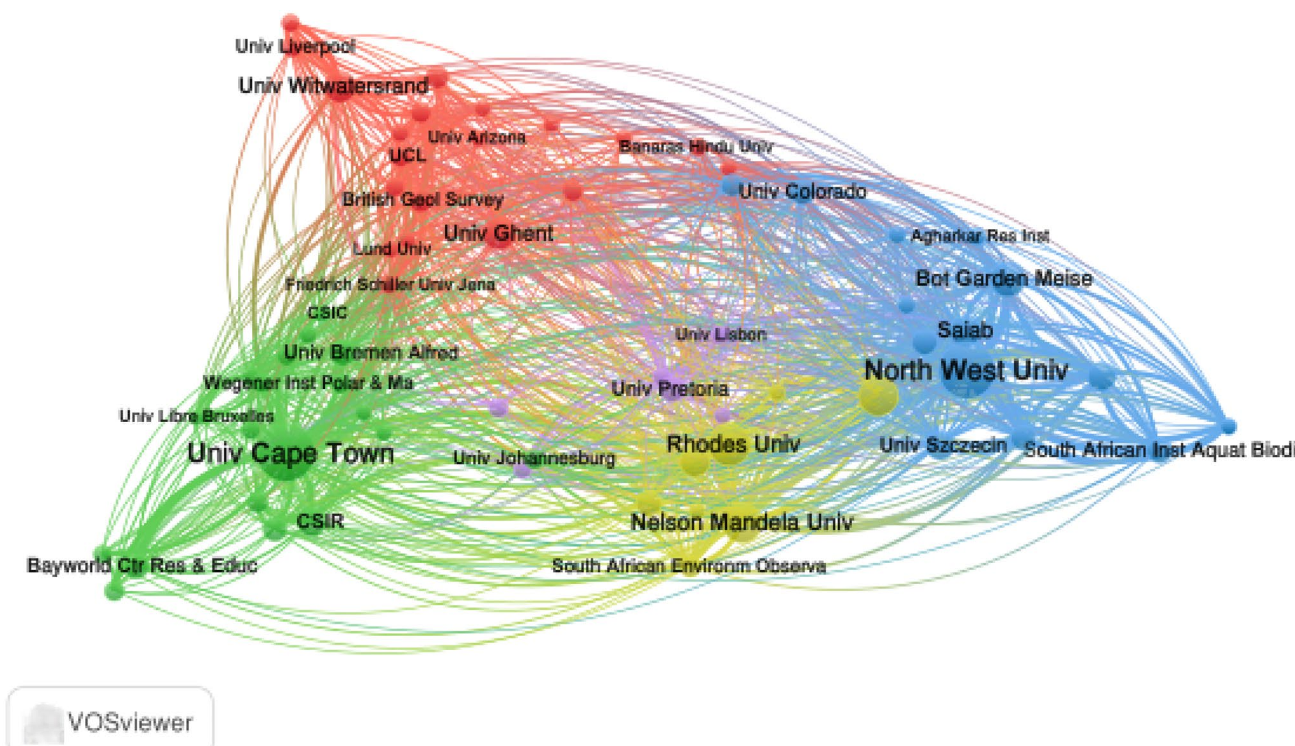

Fig. 7 The bibliographic coupling of organizations: map of diatoms in water quality monitoring topics based on keywords (author keywords and keywords plus) at a threshold of 70 citations per pair of authors between January 2012 and February 2022, constructed using VOSviewer software. The size of each circle represents the frequency of that keyword, and the color of the circle represents clustering determined with VOSviewer

Table 4 The thematic areas of the search query from the Web of Science database

Rank	Research area	Count	(%)
1	Marine freshwater biology	122	26.9
2	Geosciences multidisciplinary	117	25.8
3	Plant sciences	76	16.8
4	Environmental sciences	64	14.1
5	Physical geography	60	13.2
6	Oceanography	53	11.7
7	Ecology	38	8.2
8	Multidisciplinary sciences	24	5.3
9	Limnology	20	4.4
10	Palaeontology	19	4.2
11	Biodiversity conservation	15	3.3
12	Water resources	15	3.3
13	Microbiology	11	2.4
14	Meteorology atmospheric sciences	10	2.2
15	Geology	8	1.8
16	Biology	6	1.3
17	Geochemistry geophysics	6	1.3
18	Biochemistry molecular biology	5	1.1
19	Biotechnology applied microbiology	5	1.1
20	Evolutionary biology	5	1.1
21	Fisheries	4	0.9
22	Toxicology	4	0.9
23	Zoology	4	0.9
24	Anthropology	3	0.7
25	Chemistry multidisciplinary	3	0.7

Research themes and keywords analysis

Pesta et al. (2018) documented that keywords represented the author's important perception in the article and provides information of the patterns of a particular research topic, therefore, we analyzed the keywords in the present study. Additionally, according to Chen et al. (2019) and Sweileh (2020) keywords can be used in the categorization of the thematic research areas of the search query focusing on their relationship and similarity. Further, Chen and Xiao (2016) argued that keywords showed knowledge concept of a given search and simultaneously provide a definition of their research domain structure. Therefore, in the present study, keywords analysis indicated the most popular thematic areas covered by the search query. For instance, diatom taxonomy was related to new species, morphology, Bacillariophyta, and freshwater in our present study based on VOS viewer software clustering. This is evident through a study by Taylor et al. (2014) working in Ntumbachushi Falls on Ngona River in Zambia who discovered a new species *Actinellopsis murphyi*, a freshwater species belonging to phylum Bacillariophyta. Morphologically, the taxon is a small-sized diatom distinguished from similar species due to possession of a distinct valve, typically almost straight ventral valve margin, comparable to *Eunotia rudis* discovered at Yangambi in Congo (Cocquyt et al. 2016).

Diatom evolution were clustered together with diatom records, variability, sediments, climate, climate-change, holocene, late pleistocene, organic matter and diatom dynamics VOS viewer software. This is supported by a study by Taylor et al. (2014) who showed a disjunct distribution between *Actinellopsis murphyi* isolated from Ntumbachushi Falls on Ngona River in Zambia and the 50 million year old fossil of the taxon *Actinellopsis giraffensis* from the Canadian Arctic. This is puzzling since, the Canadian Arctic of the Eocene era has been documented as remarkably different from present day due to climate-change, with many tropical to subtropical species only identifed through fossil records obtained from the sediments (Eberle and Greenwood 2012).

Diatom indicators were related to diversity, benthic diatoms, communities, community structure, assemblages, land-use, and water quality as clustered by VOS viewer software. This is in agreement with Ndiritu et al. (2006) who studied the occurrence of epilithic diatom community in response to environmental variability in a tropical stream in Kenya, where they observed that the assessed diatom assemblages strongly responded to water quality changes with respect to concentrations of nitrites, nitrates, total dissolved solids and temperature. Benthic diatom communities at less disturbed upstream sites included *Anomoeoneis brachysira*, *Fragilaria biceps*, and *Gomphonema gracilis*; while the common taxa at agricultural sites were *Cymbella silesica*, *Nitzschia linearis* var. *linearis*, *Navicula halophila*, *N. bryophila*, *N. schroeteri, N. cryptocephala*, and *Gomphonema parvulum* (Ndiritu et al. 2006). Further, *Achnanthes minutissima* var. *saprophila, Gomphonema angustum, Navicula arvensis*, *N. subminuscula, Nitzschia umbonata*, and *N. palea*, were mostly abundant at sites dominated by urban land use, which were highly polluted by industrial and residential effluents (Ndiritu et al. 2006).

Conclusion

In this study, 481 articles on diatom research in water quality monitoring in Africa were extensively studied using the bibliometric approach between January 2012 and February 2022. Although the number of publications in this field of study in Africa is still very low compared to Europe, North America, China, and Australia, there was a remarkable yearly growth in publications, thereby demonstrating that researchers in Africa are developing interest in this very important research field. Overall, the present study has limitations, for instance, the research did not focus on the exact study sites where the field research had been conducted but outlined the institutional affiliation. In most cases, institutional affiliation is inconsistent with the location of the study area. Therefore, the inference made using institutional affiliation as a surrogate of study location may be inaccurate. Deeper synthesis of study sites, particularly those lying within same gradient of geolocations and within the same country needs to be done for purposes of precision.

Data availability The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

Code availability Not applicable.

Declarations

Conflict of interest The authors declare that they have no conflict of interest.

Consent to participate Informed consent was obtained from all individual participants included in the study.

Consent for publication Not applicable.

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