

Review

Advancements in Mine Closure and Ecological Reclamation: A Comprehensive Bibliometric Overview (1980–2023)

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Abstract: Faced with the ongoing energy transition and the escalating fragility of our natural ecosystems, ecological reclamation emerges as an imperative necessity. Investigation within this field has been in progress since the early 20th century. To gauge the advancements in this realm, elucidate the evolving research trends, and emphasize pertinent metrics, it is essential to perform a comprehensive overview of the subject. Undertaking this bibliometric study is necessary to clarify research's current state of play, grasp research hotspots, showcase outstanding researchers, and predict future research trends. In this work, 40,386 articles were retrieved from the Scopus and Web of Science databases, and bibliometric analysis was carried out using the Biblioshiny R package (Version 4.0.0, K-Synth Srl, Naples, Italy), and Python (PyCharm Community Edition 2023.2.1) to understand the progress in this research field from 1980 to 2023. The findings reveal a consistent upward trend in the publication rate within the field of mine closure and ecological reclamation over this timeframe, culminating in 6705 articles by 2022. Notably, authors and institutions from China have taken the lead, followed closely by those from the USA and Canada in terms of article publications. This prominence can be attributed to these countries' rapid economic growth and energetic transition, which has frequently come at the expense of environmental quality, and a rise in reclamation challenges. In this sense, the circular economy has risen in force recently, which highlights the withdrawal of the old linear economy. In coming research on mine closure and ecological reclamation, multi-scale ecological reclamation research should be reinforced, and social and economic concerns should be integrated. This study pinpointed current research hotspots and forecasted potential future research areas, providing a scientific baseline for future studies in mine closure and ecological reclamation.

Keywords: restoration; revegetation; phytoremediation; soil pollution; heavy metals; bibliometric



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1. Introduction

From the inception of the industrial era, there has been a continuous enhancement in the material prosperity of individuals, driven by the swift growth of the global economy [1]. However, this progress has been accompanied by pressing challenges, including global warming, environmental pollution, habitat fragmentation, and a frequent loss of biological diversity [2]. Nowadays, natural ecosystems are facing severe degradation on a global scale, leading to the breakdown of their functions, a scarcity of natural resources, and a significant drop in ecosystem-based services [3]. The issues related to the materialization and de-naturalization of natural ecosystems represent a considerable threat to the living environment of human beings, society, and global economy sustainability. In response to these challenges, organizations, institutions, and societies, both in the public and private sector, are under increasing pressure to take measures that mitigate their negative

impact on the surrounding environment [4,5]. This includes implementing sustainable practices, reducing pollution, managing waste production, and implementing a circular economy [6–9]. Organizations, institutions, and societies need to go beyond compliance with environmental regulations and actively pursue strategies and actions that contribute to the reclamation of ecological ecosystems and an ecological energy transition.

Today's practices of corporate sustainability management are not just driven by economic considerations, but also by a growing recognition of the ethical responsibilities that organizations have towards the natural ecosystems and society [10,11]. They are realizing that their actions have consequences beyond their immediate financial gains and are seeking to align their business practices with environmental stewardship [12,13].

This shift towards corporate sustainability management is driven by a combination of factors that include scientific insights about the impact of human activities on ecosystems, and economic and social demands from consumers, employees, investors, and activists for a responsible environment. In this light, mine closure and ecological reclamation refer to the processes and practices involved in recovering and restoring abandoned or depleted mining areas to minimize the environmental impacts of this industry [14–16]. This not only helps to mitigate the environmental impacts of mining but also ensures the sustainable reuse of the mined land. Furthermore, mine closure and ecological reclamation are crucial for achieving sustainable development in the mining industry [17,18].

The reclamation of ecological functions can stimulate soil formation and enhance biological activity on the surface of disposal sites [19]. Mine closure using ecological reclamation is not just important for mitigating the environmental impacts of mining, but also for fulfilling our moral responsibility to restore the land to its original state, better state, or substitute condition. Additionally, ecological reclamation is essential for ensuring the long-term productivity and sustainability of the post-mining land [14,20]. The process of implementing land reclamation in mining areas has been hindered by a variety of challenges. These include the variability of mining areas, which requires specific land reclamation schemes tailored to each mine [21].

In this context, the mine closure and reclamation of degraded ecosystems and marginal land have attracted great attention around the world [22]. The overall objective of the mine closure process, particularly through ecological reclamation, is to establish a balanced ecosystem that meets the social and economic development targets by rebuilding and replacing the ecosystem, relying both on the ecosystem's inherent restoration capacity and the intervention of various biological and physicochemical methods [23].

Although in recent years, mine closure and ecological reclamation have become a key topic of concern, research on these themes remains insufficiently systematic, and the overall progress of research needs to be further explored. At the same time, given the large number of studies in this field, relevant and recently disclosed methods, such as bibliometrics, are needed to quickly highlight the research progress. This methodology can help to understand the patterns of published scientific literature in each field of research, the journals involved, outstanding authors, the countries and institutions conducting research in a specific field, and the cooperation between them.

In addition, the analysis of keywords and themes in the literature enables researchers to identify the main topics of interest and avenues of study to be explored within a specific field. This provides them with an in-depth knowledge of their field of research while encouraging the creation of innovative ideas and the identification of new research directions.

In this study, we take advantage of an R-executable environment to examine the dynamic of research in the field of mine closure and ecological reclamation, while seeking to anticipate future trends. To do this, we used the Biblioshiny, Bibliometrix R package (Version 4.0.0, K-Synth Srl, Naples, Italy) to methodically synthesize publications relating to mine closure and ecological reclamation that appeared in the Web of Science and Scopus databases over the period from 1980 to 2023. This study aims to provide an overview of overall research and its main drivers in the field of mine closure and ecological reclamation

from 1980 to 2023, as well as explore potential research directions based on emerging trend analysis.

2. Materials and Methods

2.1. Method

Bibliometric analysis is a valuable tool for exposing publication patterns and providing an objective assessment of the state of research and the development process in different countries, scientific research institutions, or for different authors within specific fields [24]. Bibliometric methods examine the underlying knowledge structures within academic literature and present the results in a graphical form to provide a more comprehensive analysis of the field in question. Bibliometrix, created by Massimo Aria and Corrado Cuccurullo in 2017 [25], is a widely used R language package for bibliometric analysis and graphical representation of scientific data [25].

This package can analyze large bibliographic datasets and extract visualizations that promote a clear understanding of the relationships between different research areas. It also facilitates an effective understanding of guidelines for development and trends in scientific research. In our study, we used Bibliometrix to quantify various parameters such as the number of publications, geographical origins, institutions, journals, and citations. In addition, we completed these analyses by using complementary software such as Python, on PyCharm Community Edition 2023.2.1 using matplotlib, pandas, and seaborn libraries, as well as Excel (Microsoft® Excel® for Microsoft 365 MSO (Version 2311), and Datawrapper (Datawrapper GmbH, 2023)

2.2. Data Processing

Web of Science, managed by Clarivate, and Scopus are the world's largest and most comprehensive academic information resources, encompassing over 21,981 and 25,000 journals, books, and conference proceedings across a wide array of disciplines [26]. The literature searches conducted on Web of Science (WoS) and Scopus involved four distinct combinations of terms, meticulously crafted to ensure a comprehensive survey of the existing literature. As illustrated in Figure 1, a scoping exercise was executed to select the most appropriate terms for use in the bibtex files downloaded from the abovementioned database, enabling a thorough, exhaustive, and efficient search string. This exercise culminated in the following search terms used for scanning titles, abstracts, and keywords within the WoS and Scopus databases: "Mine AND closure AND revegetation"; "Mine AND ecological AND restoration"; "Mine AND reclamation"; "Mine AND waste AND management". The study period encompassed 43 years, from 1980 to 2023, with data searches and downloads conducted on 10 October 2023. Notably, we refrained from implementing any filters suggested by the WoS or Scopus portals, including categories, document types, source titles, publication stages, keywords, language, etc.

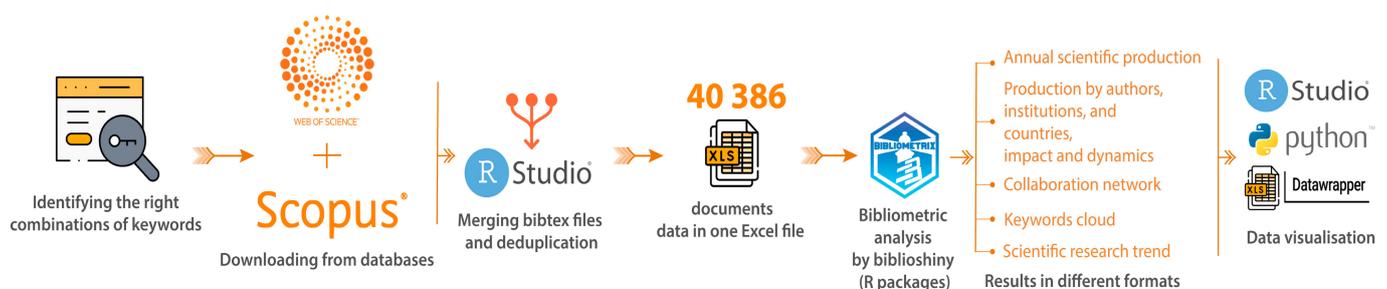


Figure 1. Schema of the Web of Science and Scopus database processing and analysis methodology.

After the removal of duplicate results using R Studio to identify and eliminate redundant entries, we successfully obtained a final set of 40,386 (Figure 2) unique references within the field of mine closure and ecological reclamation, acquired following the consoli-

dition of data from WoS and Scopus, alongside other necessary preprocessing steps. The compiled data was then stored in an Excel file.

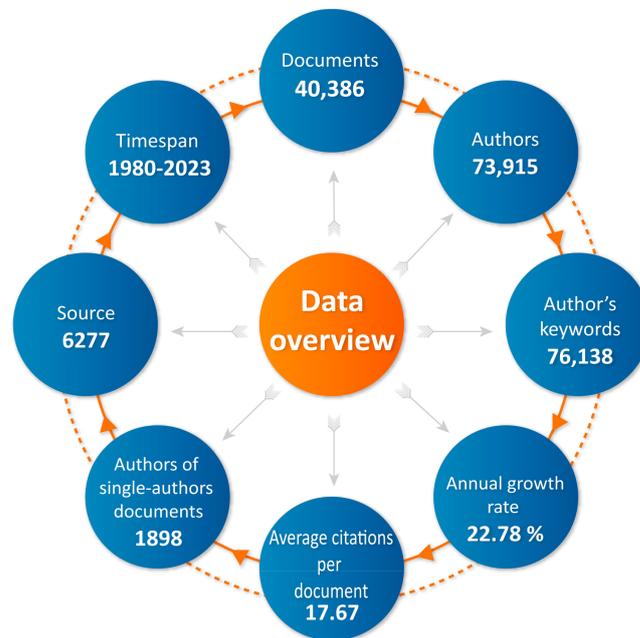


Figure 2. Overview schema of the processed data downloaded using keywords in the field of mine closure and ecological reclamation from 1980 to 2023.

Following data collection, the Excel file of the downloaded data underwent analysis using the Bibliometrix software, Biblioshiny (version 4.0.0) [25]. Our analysis was structured as follows: initially, we examined the volume and citations of documents spanning the years 1980 to 2023. Subsequently, we identified the principal journals (sources) along with their respective impact factors (IF) and dynamic, most authors in the field of mine closure and ecological reclamation, as well as the countries and institutions that dominated article publications. Thirdly, we identified the principal journals in the field. Lastly, we conducted a visual analysis of keywords and thematic trends in the field to pinpoint the most promising research topics.

3. Results

3.1. Publication Volumes and Annual Citation Dynamics

Looking over the statistics on the number of publications each year provides an illuminating insight into the research process related to mine closure and ecological reclamation. Over the period from 1980 to 2023, a marked trend emerged from these data (Figure 3), a steady growth in the number of publications, reflecting a growing interest in the fields of mine closure and ecological reclamation. During the first part of this period, from 1980 to 2004, the number of articles published was relatively modest, with less than 100 publications per year all over the world, representing 23% of the total number of articles during this time range. This can be described as an ‘initial phase’ characterized by a gradual increase in the number of published articles. Then, from 2004 to 2013, we observed a significant increase, from 114 to 420 per year. This is indicative of a period when research into mine closure and ecological reclamation gained in importance. As scientists contributed to this field, crucial issues such as environmental policies, ecological reclamation principles, phytotechnologies, and other aspects became more relevant, generating notable interdisciplinarity. After 2013, the growth in publication frequency in the field of mine closure and ecological reclamation continued substantially, reaching a total of 6705 articles in 2022. This significant increase testifies to the growing importance attached to these issues within the scientific community.

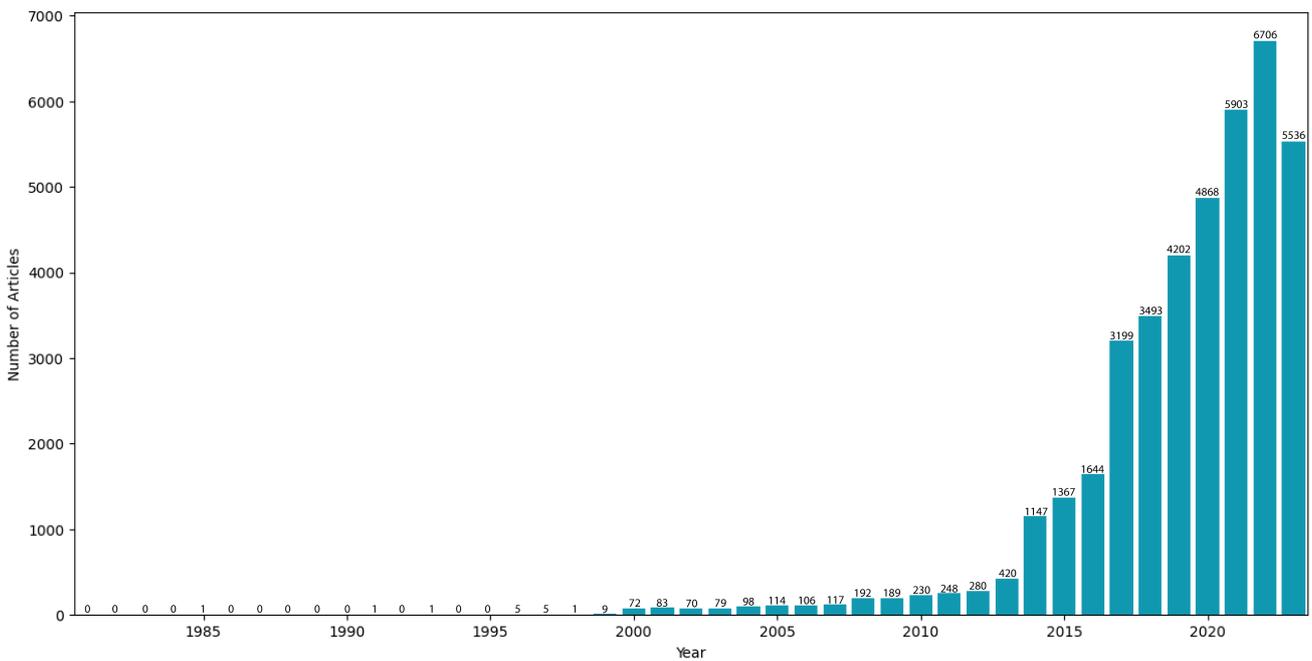


Figure 3. Dynamic of scientific publications on ecological reclamation from 1980 to 2023.

The annual citation frequency for literature in the field of mine closure and ecological reclamation exhibited a dynamic pattern of growth, as presented in Figure 4. Notably, the citation frequency per article remained relatively low between 1980 and 2000. However, during the first decade of the 21st century, the average citation frequency saw fluctuations within the range of 38.32 to 62.96, with a remarkable peak in 2002. It is worth noting that this citation frequency is closely linked to the evolutionary phase of research in this domain. In essence, the increasing number of articles over time underscores the expanding influence and significance of the field of mine closure and ecological reclamation.

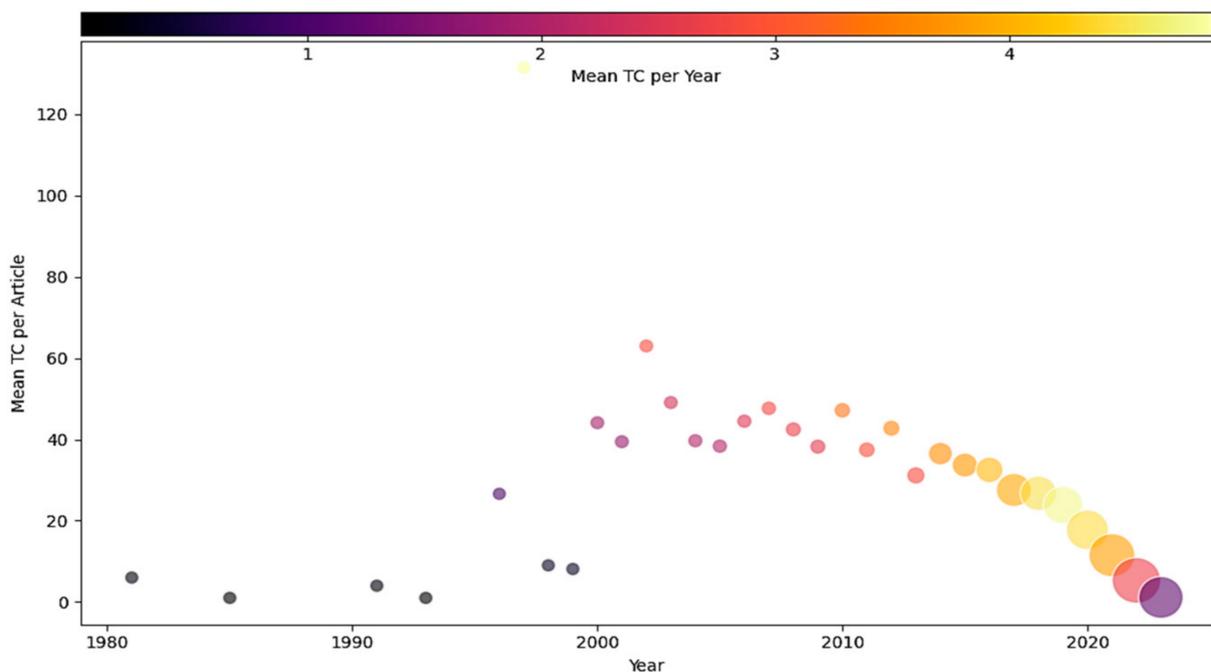


Figure 4. Dynamic of scientific citations of the articles published on mine closure and ecological reclamation from 1980 to 2023.

3.2. Research Trends in the Field of Mine Closure and Ecological Reclamation

3.2.1. High-Frequency Keyword Analysis

Keywords serve as valuable tools for summarizing and elucidating the content of a research article. In particular, the analysis of high-frequency keywords plays a pivotal role in unraveling the fundamental components of knowledge concepts, shedding light on the prevailing issues within the field of mine closure and ecological reclamation research. To visually represent this, we employed a keyword cloud graph (Figure 5), where larger font sizes signify higher keyword occurrence frequencies.

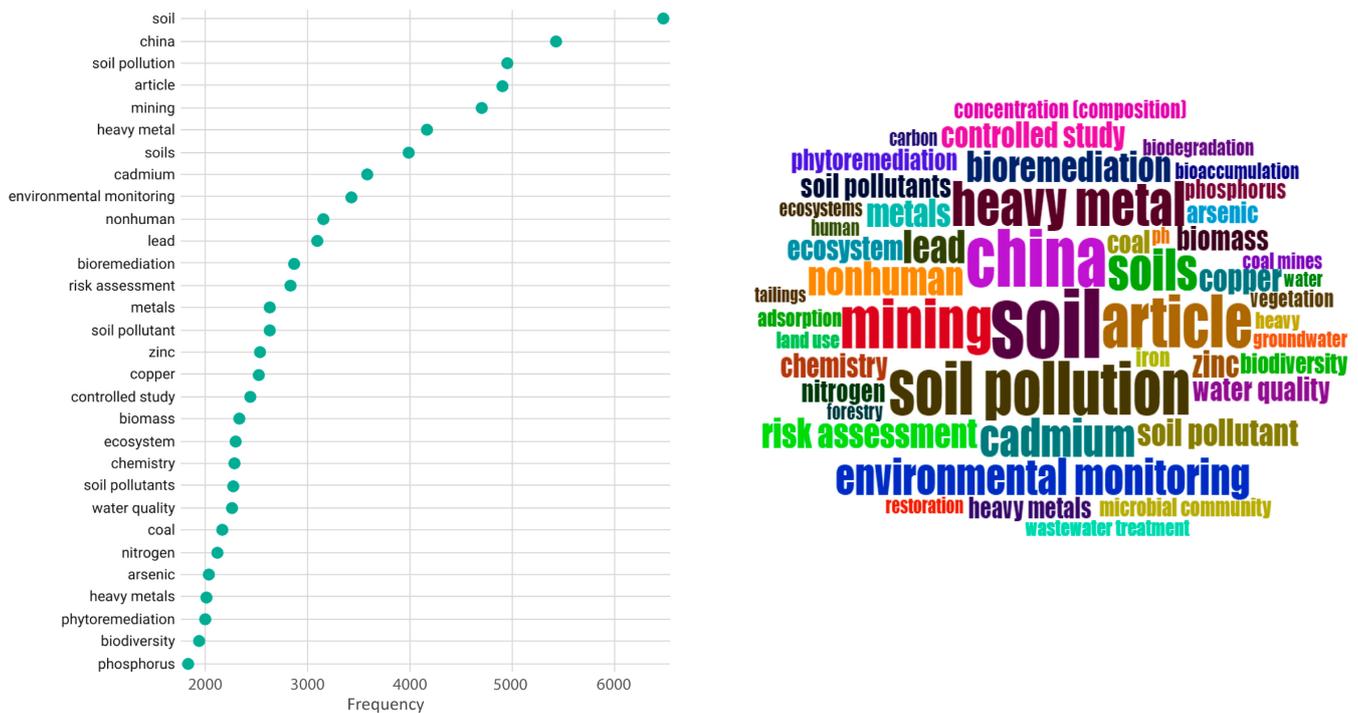


Figure 5. High-frequency keyword network visualization in the field of mine closure and ecological reclamation from 1980 to 2023.

Notably, the high-frequency keywords encompassed crucial terms such as “soil”, “China”, “mining”, “soil pollution”, “heavy metal”, “environmental monitoring”, “cadmium”, and “bioremediation.” The presence of these keywords reflects their relevance to global ecological reclamation research.

It is important to note that vulnerable ecosystems, often marred by anthropogenic activities such as mining, share a strong interconnection with the realms of mine closure and ecological reclamation. Different ecological reclamation strategies apply to various ecosystem types, including heavy metal-contaminated soils, abandoned mines, marginal lands, and more, further underlining the multifaceted nature of this critical field.

Figure 6 provides a comprehensive co-occurrence analysis of authors’ keywords, offering valuable insights into the interconnectedness of terms within the realm of mine closure and ecological reclamation research. This co-occurrence analysis serves as a powerful tool for gaining a deeper understanding of the pivotal keywords in this research area.

In this visualization, the size of each circle corresponds to the frequency of the term’s occurrence. Larger circles represent keywords that appear more frequently in the general list of an article’s keywords. Furthermore, the proximity of terms within the diagram reflects the strength of their connection, with shorter distances indicating a more robust association. The connection strength itself is contingent on the frequency of joint occurrences of these terms. To enhance clarity, colors are employed to denote distinct thematic clusters within the network of terms. The concept map reveals a complex interplay of keywords, with three prominent thematic clusters emerging. The first, denoted in red, encompasses topics related

to revegetation, restoration, biodiversity, and ecosystems. The second cluster, colored in blue, is closely aligned with the first cluster and is centered around keywords related to soil, soil pollution, heavy metals, and cadmium. The third cluster, identified by its green color, pertains to soil properties such as phosphorus, carbon, and nitrogen.

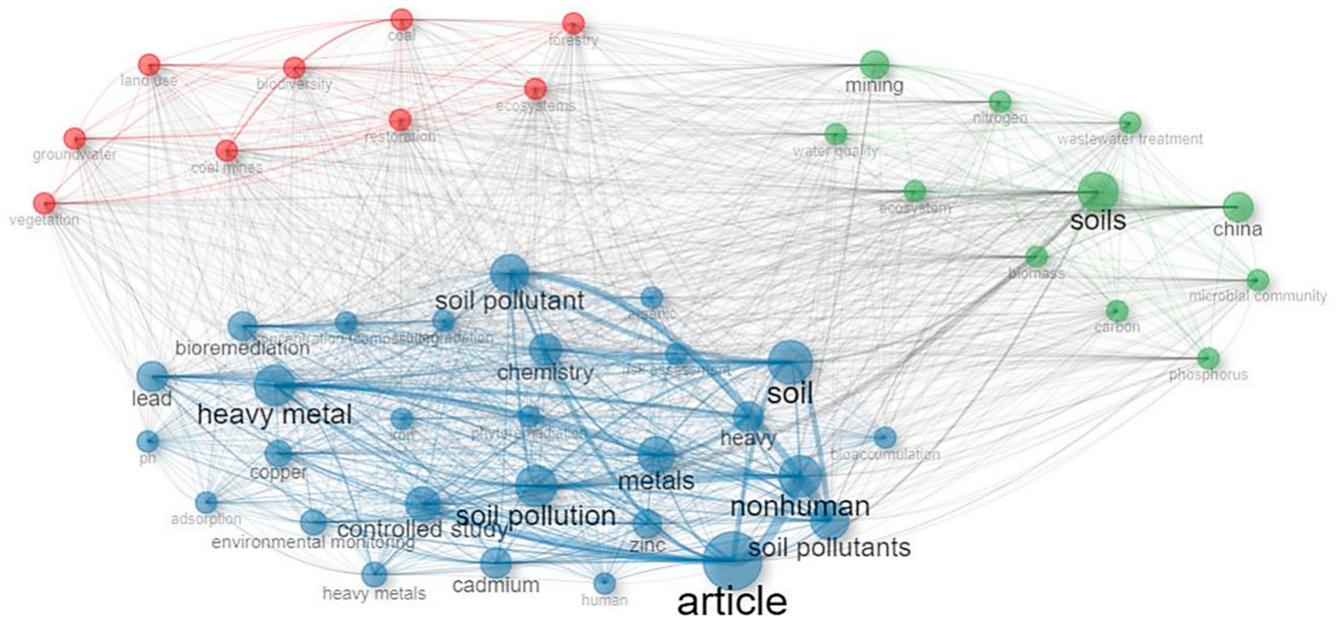


Figure 6. Networking analysis co-occurrence of keywords of the articles published in the field of mine closure and ecological reclamation from 1980 to 2023.

This visual representation effectively illustrates the intricate web of connections among the key terms in this field of study. It highlights the high connectivity between different components of the environments emphasized in this field of study, and sheds light on the complexity that encompasses mine closure and ecological reclamation studies.

3.2.2. Thematic Trends

Thematic trends are identified by the frequency change of the keywords, as shown in Figure 7. The colored squares indicate that the keywords appeared more frequently in that period. From 1980 to 2001, heavy metals, contamination, rehabilitation, and revegetation were the hot keywords. This indicates a surge in research concerning the environmental consequences of mining operations, with a specific emphasis on the enduring effects of abandoned mining sites.

From 2002 to 2011, ecological restoration, water, acid mine drainage, and reclamation became hot keywords. Driven by the concepts of sustainable development and green development, mining companies, engineers, and researchers began to take interest in and practice so-called ecological restoration, and reclamation that began to take the place of revegetation and rehabilitation. The practice of ecological reclamation in the mining environment has favorably promoted research related to water in this sector as well as innovations in its treatment technology.

From 2012 to 2023, reclamation took precedence over revegetation. This shift underscores the broadening scope of mine reclamation, extending beyond mere revegetation to encompass multiple facets of the environment. It now includes considerations related to water, soil, landscape, biodiversity, economics, and social dimensions. In this period the concept of circular economy in the mining sector gradually became the focus of this research domain.

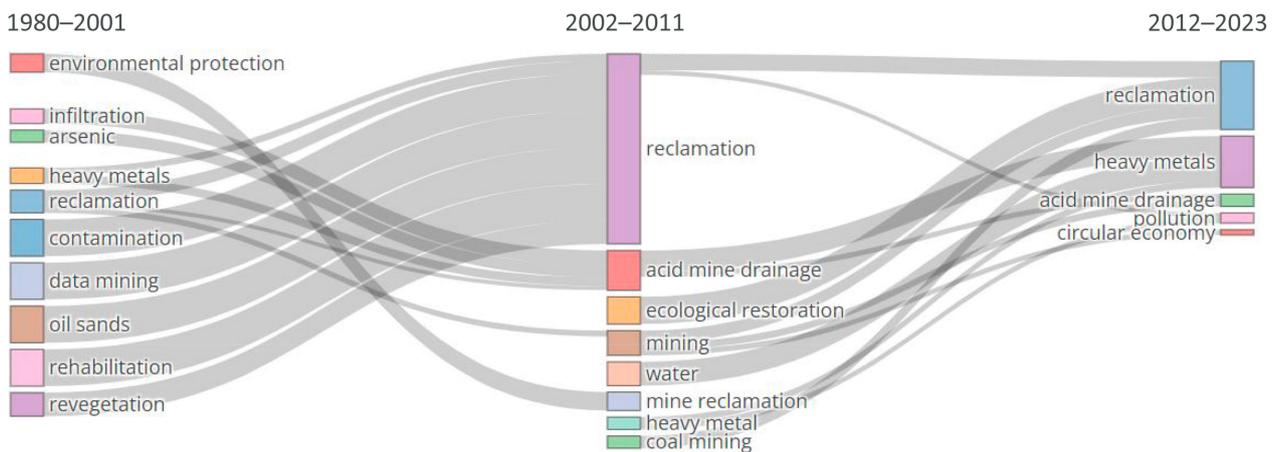


Figure 7. Thematic trends based on authors’ keywords use in the article published in the field of mine closure and ecological reclamation from 1980 to 2023.

The emergence of this term can be attributed to a fundamental shift in economic thinking and practice. It also reflects heightened awareness and efforts in terms of safeguarding environmental issues, as well as the promotion and adoption of cleaner production policies. It marks the departure from the traditional linear economic model, where resources are used and disposed of, towards an innovative circular model. In this circular model, there is a deliberate emphasis on not only minimizing waste but also on recovering and effectively utilizing by-products, thereby promoting sustainability and resource efficiency.

3.3. Main Journals and Relevant Documents in the Field of Mine Closure and Ecological Reclamation

This section shows the most popular journals in the field of mine closure and ecological reclamation and analyzes their leading indicators (Figure 8). The most productive journals were Science of the Total Environment, Environmental Sciences and Pollution Research, Journal of Environmental Management, Sustainability-MDPI, and Chemosphere. These journals are all classified Q1, with impact factors ranging from 3.9 to 9.8, encompassing a range of disciplines related the ecological reclamation, including environmental engineering, waste management and disposal, pollution, environmental chemistry, management, monitoring, policy, and law.

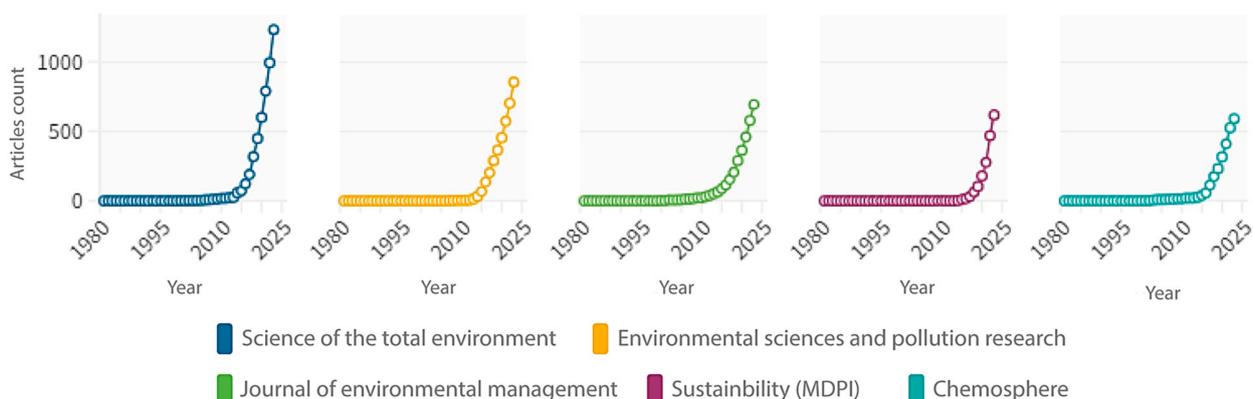


Figure 8. World leading journals in the domain of mine closure and ecological reclamation from 1980–2023.

Table 1 provides the most globally cited documents in the research field of mine closure and ecological reclamation from 1980 to 2023. It was seen that Li Z. et al. (2014) [27] from China had the highest global citations with 2139 citations with his article published

in the Sciences of Total Environment, followed by the article titled ‘Remediation of heavy metal(loid)s contaminated soils—To mobilize or to immobilize?’ published by Bolan et al. (2014) [28] in the Journal of Hazardous Materials with 1498 citations, and the document published by Kumpiene et al. (2008) [29] in the prestigious journal of Waste Management.

Table 1. Most globally cited documents related to the mine closure and ecological reclamation scope.

Document	Reference	Year	Global Citations	Country
Li Z, 2014	[27]	2014	2139	China
Bolan N, 2014	[28]	2014	1498	Australia
Kumpiene J, 2008	[29]	2008	1176	Sweden
Gadd GM, 2010	[30]	2010	1157	United Kingdom
Wang J, 2019	[31]	2019	1056	China
Carolin CF, 2017	[32]	2017	1032	India
Liu L, 2018	[33]	2018	962	China
Khalid S, 2017	[34]	2017	826	Pakistan
Singh R, 2015	[35]	2015	820	India
Mendez MO, 2008	[36]	2008	752	USA
Wong MH, 2003	[37]	2003	742	Hong Kong
Azubuike CC, 2016	[38]	2016	709	Nigeria
Vangronsveld J, 2009	[39]	2009	696	Belgium
Mahar A, 2016	[40]	2016	650	China
Gann GD, 2019	[41]	2019	649	USA
Palansooriya KN, 2020	[42]	2020	619	Republic of Korea
Hashim MA, 2011	[43]	2011	613	Malaysia
Yan A, 2020	[44]	2020	602	Singapore
Ojuederie OB, 2017	[45]	2017	592	South Africa
Mao X, 2015	[46]	2015	581	China

At the local scale, 62% of the Moroccan authors that have global citations equal to or exceeding 10, in the research field of mine closure and ecological reclamation, are presently affiliated with the University Mohammed VI Polytechnic in Ben Guerir, Morocco. That means that this institution is the actual hub of the most productive author in the research related to mine closure and ecological reclamation. These authors’ disciplines cover mineral processing, waste valorization and management, circular economy, geology, botany and plant ecology, microbiology, and plant physiology.

3.4. Main Institutions and Countries Conducting Research in the Field of Mine Closure and Ecological Reclamation

Figure 9 serves as a visual representation of the leading global institutions in terms of their scientific publications in the field of study. Notably, the most prominent authors are predominantly affiliated with key institutions, with the China University of Mining and Technology leading the pack with 1439 articles. Other significant contributors include the University of Chinese Academy of Sciences (677 articles), the China University of Geosciences (491 articles), the University of Alberta (445 articles), and the Chinese Academy of Sciences (444 articles), as presented in Figure 9.

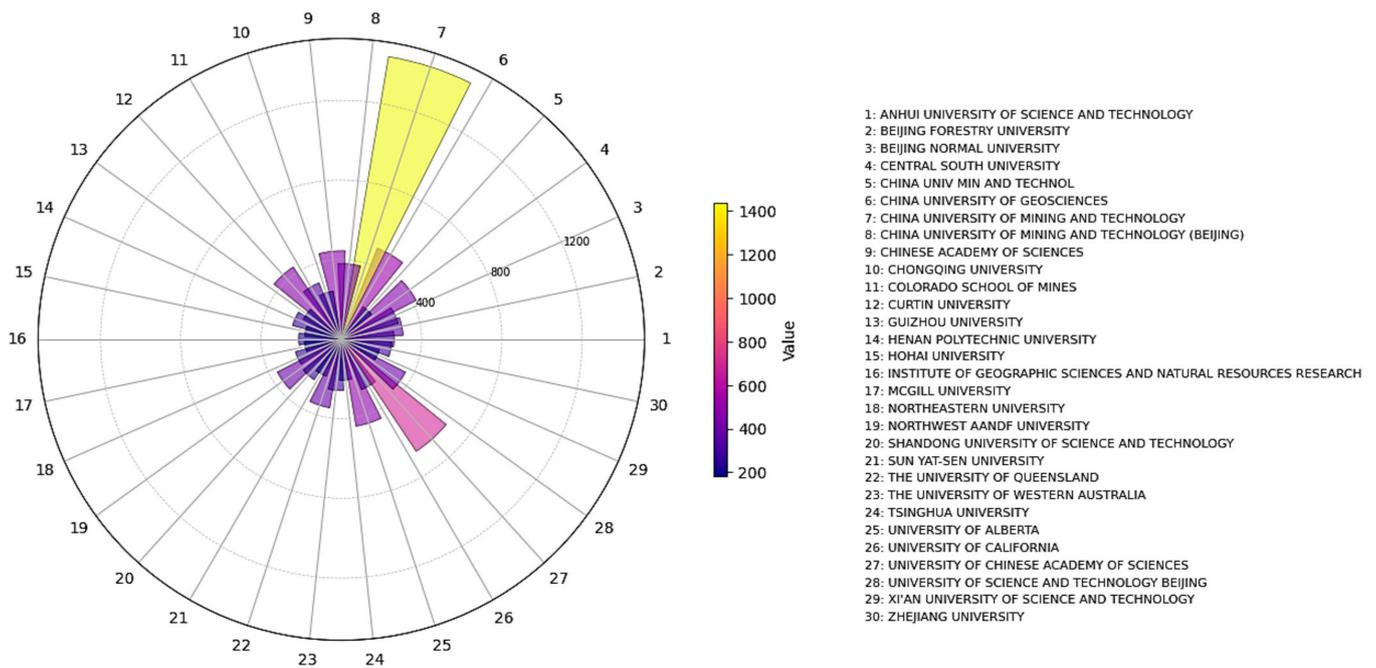


Figure 9. World-leading institutions in scientific production in mine closure and ecological reclamation from 1980 to 2023.

Expanding the scope to encompass universities in Africa relevant to the research criteria, the University of Johannesburg emerges as the primary affiliation, with 101 articles to its credit. In Morocco, the University of Cadi Ayyad in Marrakech is the most notable institution, with 59 articles, closely followed by the University Mohammed VI Polytechnic, which has contributed 42 articles.

We have also identified the top five countries that have been at the forefront of research in the field of mine closure and ecological reclamation, primarily based on the volume of literature available, as illustrated in Figure 10. While research on mine closure and ecological reclamation has been conducted by numerous countries globally, it is evident that the lion's share of publications hails from China, the United States of America, Canada, Australia, and India. These top five nations collectively contributed significantly, with China leading the pack at 25.5% (equivalent to 13,979 publications), followed by the United States of America at 11.6% (6380 publications), Canada at 6.4% (3494 publications), Australia at 5.5% (3021 publications), and India at 4.8% (2645 publications). This remarkable distribution highlights their substantial role in advancing research in the field of mine closure and ecological reclamation.

The Central and Eastern European region is represented by eight countries among the first fifty most productive countries. The top five contributors from this region include Poland with 1868 publications, the Czech Republic with 723, Romania with 276, Ukraine with 272, and Austria in the fifth position with 260 publications.

Within this extensive repository of publications originating from different continents like America, Australia, Asia, and Europe, it is worth noting that contributions from African countries are relatively limited. Specifically, only four countries, namely South Africa, Egypt, Nigeria, and Morocco, have exceeded the 200-publication mark. The leading countries in this context are indicative of the strong influence and capacity of their affiliated academic institutions in shaping the research landscape.

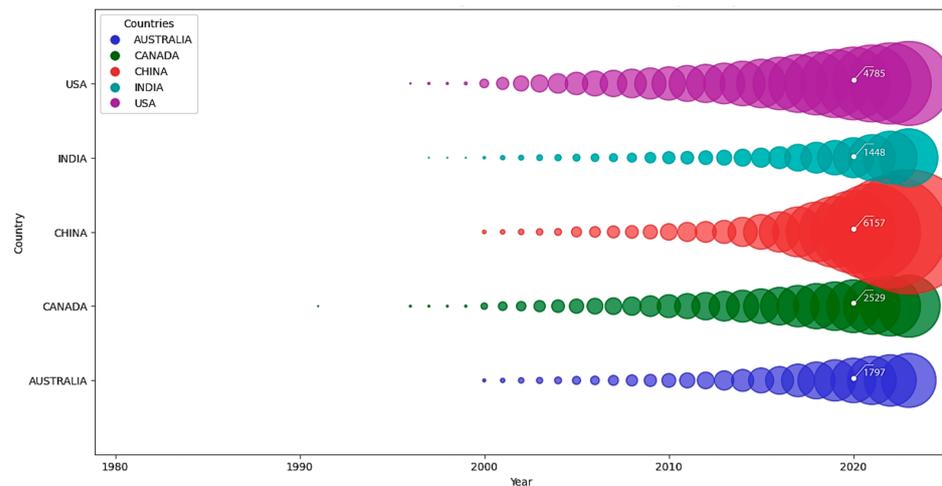


Figure 10. Volume of published articles by top five countries on mine closure and ecological reclamation from 1980 to 2023.

The analysis of single-country populations (SCP) and multiple-country populations (MCP) offers a deeper insight into a country’s scientific research capabilities. Over the study period (1980–2023), China emerged as a frontrunner with the highest MCP, totaling 225 articles, and the highest SCP, encompassing 10,957 articles. In contrast, Canada exhibited a slightly higher MCP (127) compared to the USA (108), as indicated in Figure 11. This dichotomy implies that Chinese and Canadian researchers actively engaged in international collaborations, while their American counterparts predominantly pursued independent research efforts.

Turning our focus to the African continent, the top five countries in terms of MCP for mine closure and ecological reclamation research are as follows: South Africa takes the lead with 26 articles, closely followed by Morocco with 16 articles, Egypt with 6 articles, and Nigeria and Ghana, both ranking fifth with 4 articles each. This regional perspective underscores the growing global significance of mine closure and ecological reclamation research, emphasizing the pressing need for regional and global cooperation. Such collaboration is essential in fostering partnerships between developed and developing nations, enabling the exchange of expertise, and propelling the advancement of research in the field of mine closure and ecological reclamation on a worldwide scale.

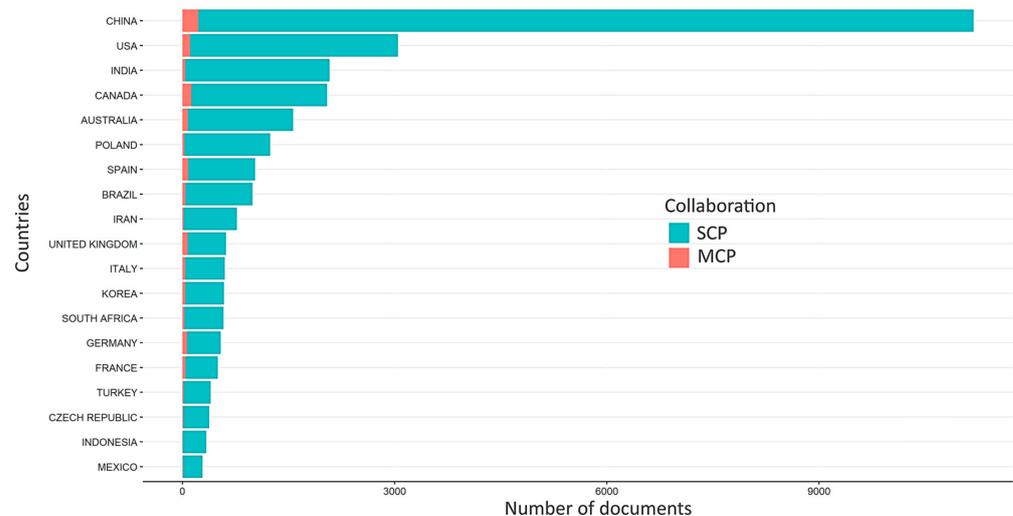


Figure 11. Countries of the corresponding authors of the articles published from 1980 to 2023. SCP: Single country publications (intra-country); MCP: Multiple country publication (inter-country).

4. Discussion

Ecosystems have a dual role, not only do they provide a wide range of primary materials and products directly exploited by humans, but they also perform a multitude of essential functions. These roles include storing carbon, regulating the climate, purifying pollutants, preserving soil and water, preventing wind erosion, and maintaining biodiversity as well [47]. As such, ecosystems ensure the long-term sustainability of human communities and the economy. As mentioned in the introduction, the energy transition, the rapid development of industry, and the growth of electronic waste volume require more industrialization and production at all levels, including the mining sector, that lead to ecosystem degradation [48]. Such degradation and distribution oscillate around one or several aspects of ecosystem services. At the same time, academic research on ecological reclamation has increased significantly over the past ten years, with significant positive trends in environmental policies.

The findings reveal a consistent upward trajectory in the number of articles within the field of mine closure and ecological reclamation, a trend that has been steadfastly increasing since 2005. Remarkably, after this pivotal year, mine closure and ecological reclamation attracted heightened attention, fostering an accelerated development in this research domain.

Several theories can be put forward to explain this renewed interest. These include the growing awareness of ecological issues, the implementation of sustainable development goals, and an increasing sense of environmental responsibility within industries, among other factors. Additionally, the emergence of remediation techniques has played a pivotal role. These encompass diverse approaches, ranging from physical methods like soil washing, surface capping, soil replacement, encapsulation, and nano-remediation, to chemical remediation techniques involving the introduction of reactive substances, vitrification, chemical fixation, and electrokinetics [49]. Moreover, biological technologies, known as phytoremediation techniques, have gained prominence. This approach leverages the innate capabilities of plants and microorganisms to absorb, break down, and transform pollutants [50].

The co-occurrence of keywords and the pattern of development of this theme also show that the four main keywords in this area are bioremediation, soil, heavy metals, and recovery. The main new directions in research include mine water treatment, rare earths removal, cadmium bioavailability, marginal land reclamation, and mining land revitalization. In the future, it is imperative and beneficial to strengthen collaborative efforts among institutions around the world, promoting comprehensive research on ecological reclamation through a multifaceted approach.

Asian nations, with China at the forefront, along with the United States of America and Australia, have spearheaded advancements in the field of mine closure and ecological reclamation. Their leadership is attributable not only to their pioneering research but also to the extensive and synergistic partnerships between academia and industry. As well, their active involvement underlines the crucial role of the academic world in advancing research in the field of mine closure and ecological reclamation. Presently, a substantial disparity exists between the state of mine closure and ecological reclamation in developing countries compared to their more developed counterparts. Consequently, it holds great significance in bolstering international cooperation to facilitate the sound progress of ecologically sustainable mining practices [51].

However, most phytoremediation studies, particularly in Morocco, are limited to screening the phytoremediation capacities of plants growing in or around mining areas and do not go as far as using the most capable plant species to revegetate land after mining toward their reclamation. In the future, the research scope of mine closure and ecological reclamation should also be transformed from the perspective of screening and impact evaluations to concrete field solutions involving multiple methods and techniques, especially in African countries [52,53]. Indeed, mine closure and ecological reclamation extend beyond their ecological and environmental aspects; they encompass significant social and

economic dimensions. This entails considerations such as economic losses, financial investments, reclamation expenses, and the management of resources and development [48]. The integration of conceptual frameworks and research methodologies from both the natural sciences and humanities into mine closure and ecological restoration projects is a growing area of focus [54]. Consequently, mine closure and ecological reclamation are not only scientific endeavors but also encompass essential social and economic perspectives.

Multidisciplinary research in the field of mine closure and ecological reclamation is still in its very nascent stages, particularly within the African context [17]. While the existing findings have been promising in terms of characterizing environmental issues and exploring various methods and techniques, there remains much work to be done. This article aims to elucidate the academic landscape surrounding mine closure and ecological reclamation, assisting scholars in identifying key areas of focus and providing a foundation for more in-depth investigations.

While this paper makes a meaningful contribution to the field, it does have some limitations. Notably, we focused on specific keywords such as “Ecological reclamation” and “Mine closure” overlooking other relevant terms like “phytoremediation”, “waste management”, “ecological rehabilitation”, and “marginal land reclamation” that are also pertinent to the domain of mine closure and ecological reclamation. Additionally, our study considered the period from 1980 to 2023, although valuable research may have been published before 1980. Our research relied on two primary bibliographic data sources, the Web of Science and Scopus while omitting articles from PubMed, Dimensions, Microsoft Academic, and other databases. In forthcoming research, we intend to explore methods to integrate additional databases and broaden our research scope considering the ongoing discourse. Furthermore, the field of mine closure and ecological reclamation encompasses a multitude of aspects and issues. Future work will delve into the evolving trends in crucial subtopics within this domain.

5. Conclusions

This article offers a comprehensive bibliometric analysis of the evolution of mine closure and ecological reclamation research. It illuminates publication trends, prominent research journals, leading institutions, key countries, and pivotal articles. Our exploration extends to the development of research focal points, thematic trends, and a forward-looking assessment of research directions.

From 1980 to 2023, the number of articles dedicated to mine closure and ecological reclamation research experienced consistent growth, accompanied by an increase in the average annual citation count. Distinguished articles found their home in esteemed journals. China, the United States, and Canada have emerged as leaders in this field, followed by Australia and India. It is worth noting that American researchers often gravitate towards independent research, whereas their Chinese and Canadian counterparts are more engaged in international collaborations. Predominant institutions in this field are rooted in China, with China University of Mining and Technology leading the way on a global scale, and Cadi Ayyad University taking the helm locally.

Prominent journals in this domain include *Science of the Total Environment*, *Environmental Sciences and Pollution Research*, and *Journal of Environmental Management*. These findings underscore the vast landscape of mine closure and ecological reclamation research, with soil, mining, pollution, heavy metals, and bioremediation as central themes.

Looking ahead, there is an urgent need to amplify research efforts in the field of ecological reclamation across various scales and transcending traditional boundaries. Moreover, research in the realm of mine closure and ecological reclamation must seamlessly integrate social and economic dimensions to effectively address the emerging challenges posed by the ongoing energy transition. Our objective is to illuminate the intellectual ground within the academic community, aiding our colleagues in identifying the current focal points and directions in mine closure and ecological rehabilitation, while providing a robust foundation for more comprehensive research endeavors in this critical field.

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