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RESEARCH ARTICLE

Bibliometric Mapping of Impacts in Erosion Risk Management Research (1992-2025).

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Abstract

Despite the growing body of research on erosion risk management (ERM), a significant gap remains in studies specifically examining ERM through bibliometric analysis. This study bridges this gap by analyzing 81 ERM-related publications retrieved from the Scopus database using bibliometric techniques, VOSviewer, and Microsoft Excel. The analysis reveals that a limited number of prominent authors, affiliations, countries, and funding sources characterize ERM research. The United Kingdom dominates funding of ERM research, with the Environment Agency, Bristol, emerging as the organization with the most ERM-related publications, and India, overall, taking the lead as the country most associated with ERM research. The triad of Avanzi J.C., Curi N., and Viola M.R. has the most impactful works based on citation counts, with Catena having the reputation of the most cited journal concerning ERM research. A notable increase in ERM publications, post-COVID-19, suggests growing interest in sustainable development and risk assessment techniques like GIS. Keyword Co-occurrence Analysis (KCA) identified four major research hotspots, which informed the identification of research gaps and future research directions. This study provides a foundation for further exploration of ERM and its potential to drive sustainable development.

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Keywords: Analysis, Bibliometric, Erosion, Management, Publications.

1. Introduction Font size Minion Pro 10 bold

Erosion is the geological process involving the wearing away of earth materials and their displacement by natural forces such as wind or water (Ojo & Adedayo, 2024). Soil erosion, influenced by factors such as climate, topography, vegetation, and tectonic activity, significantly contributes to large-scale damage in existing built-up settlements and agricultural lands, causing disruptions to livelihoods and hindering agrarian productivity. It is also a major cause of sand sedimentation in water bodies, leading to associated pollution and the destruction of aquatic life (Rotimi, 2019; Prakasam & Pathak, 2025). In the face of increasingly extreme climate events owing to climate variations and inadequate resilience measures, rainfall fluctuations significantly influence soil erosion and ultimately increase erosion hazards by damaging healthy ecosystems. Erosion has been identified as one of the most destructive land degradation hazards, primarily responsible for the reduction in the quality of soil health (Chen et al., 2021). Indeed, studies have estimated that about 24 billion tons of fertile soil are lost to soil erosion on a yearly basis (United Nations, 2019). Beyond the loss of fertile land and natural capital and the distortion of ecosystem services, soil erosion equally brings about increased pollution, as a result of sand sedimentation. The silt deposit does not just pollute water bodies; it also culminates in their clogging, with the attendant destruction of aquatic life. Most importantly, lands impacted by erosion are often less able to hold onto water. Hence, they become vulnerable to floods (Senanayake et al., 2024).

Globally, communities have had their fair share of exposure, susceptibility, and extremely low resilience to erosion risks (Ogunnaike, 2023). This is often manifested in how erosion represents a great risk factor for road failures, damage to buildings, and agricultural lands (Ubido et al., 2020). Environmental hazards like erosion manifest within settlements because of the inability to proactively devise erosion risk management (ERM) strategies in the form of master plans or disaster risk maps that specify hazard-prone areas and guide sustainable development. ERM is about deploying proactive strategies and scientific techniques for identifying erosion-prone areas, assessing associated risks, and implementing strategies for mitigating and remediating their impacts (Kucuker & Giraldo, 2022; Mahmood, 2024; Tkeshelashvili, 2024). As predicted by Mullan et al. (2012), erosion incidents are likely to increase as a result of climate change and a more active hydrologic cycle. Climate change is profoundly affecting both social and environmental systems in unprecedented ways (Morshed, 2025). Projections suggest that by 2100, the Earth's average temperature could rise by 1 to 5.7 degrees Celsius above pre-industrial levels, accompanied by a potential sea-level rise of 0.28 to 1.01 meters. This poses significant threats, including increased erosion due to more frequent and severe flooding, as well as heightened food insecurity (IPCC, 2022). Effective governance now prioritizes addressing these complex climate-related challenges, recognizing the urgent need for sustainable solutions to protect communities and ecosystems from the escalating impacts of climate change, including erosion (Echendu,2020). Addressing erosion is crucial in the context of climate change, as it can help mitigate the effects of flooding, landslides, and soil degradation. Effective governance and sustainable land management practices can help reduce erosion and promote resilience in the face of climate change.

For countries within tropical and subtropical zones that are yet to have adequate climate resilience measures, this implies a serious vulnerability challenge in the face of the inevitable intensification of rainfall events. Because of the many impacts of soil erosion, its prevention has been described as critical to the actualization of the Sustainable Development Goals (SDGs) by 2030. Notably, sustainable management of soil resources is related to SDGs 1 and 2 (poverty eradication), SDG 3 (good health), SDGs 6 and 14 (sanitation and blue economy), SDG 13 (climate hazards mitigation), and SDG 15 (sustainable use of ecosystems) (Senanayake et al., 2024). Therefore, erosion risk management strategies are essentially geared towards bringing about improvement in sustainable land management, preventing the distortion of ecosystem services, preserving natural capital, mitigating climate change, and fundamentally mitigating multidimensional insecurities, most especially along the dimensions of food, energy, and water. In order to mitigate erosion risk as a strategy for actualizing critical SDGs, reconstruction of policies and governance based on historical and forecast data is imperative. Being a very critical area of sustainable development, several studies (Wischmeier & Smith, 1978; Renard et al., 1997; Awokola, 2002; Abdulfatai et al., 2014; Ganasri & Ramesh, 2016; Gholami et al., 2021; Rotimi, 2019; Ghaith & Li, 2020; Lamidi et al., 2020; Ajibade et al., 2020; Woldemariam et al., 2023; Ezeh et al., 2024; Ahaneku et al., 2024) have been conducted in the area of erosion risk management (ERM). However, many of the studies focus on small geographical areas, neglecting spatiotemporal patterns of erosion risk at the zonal or regional level. Many of the studies equally lack comprehensive assessments of erosion risk, particularly in the context of climate change and land use variations. Moreover, there are inconsistencies in procedures and methodologies deployed in assessing risk. Existing studies have mostly deployed empirical models such as the Revised Universal Soil Loss Equation (RUSLE). However, these models have linear structures, are time-consuming, expensive, less accurate, and do not simulate the physical processes of erosion advancement. Further, a few of the existing studies conducted to assess erosion risk have applied data-based machine learning approaches that afford smarter, faster, cheaper, and more accurate predictions of soil erosion vulnerability, and have employed limited variables (Gholami et al., 2021; Khosravi et al., 2023; Tkeshelashvili,2024).

As the body of knowledge on ERM continues to expand, a critical assessment of the milestones established by frontier research and the understanding of prospective research vistas and developments in the field is imperative. Currently, to the best of the researchers' knowledge, systematic analyses of global research trends on ERM that leverage bibliometric techniques are limited. Hence, the focus of the study is to identify influential authors, publications, and institutions shaping the field of ERM. Through network analysis and keyword co-occurrence examination, this study uncovers hidden patterns and trends in the existing body of knowledge and reveals under-explored areas, emerging trends, and potential research avenues. By leveraging bibliometric techniques, this analysis provides a panoramic view of global research trajectories, making it accessible to a broad audience. The findings will serve as a valuable resource for researchers, policymakers, and funding bodies, enabling informed decisions that steer future research initiatives and developmental endeavours. Additionally, this study will guide early-career researchers in selecting promising research avenues and facilitate strategic partnerships for seasoned experts.

2. Methods

This comprehensive study embarked on an in-depth investigation of global research trends in the field of ERM, harnessing the vast potential of the Scopus database, which has been widely acknowledged as a premier platform for bibliometric analysis (Nyakuma et al., 2023). A meticulous and systematic search was conducted on April 19, 2025, yielding a substantial corpus of publications spanning three decades, from 1992 to 2025, that were specifically related to the research topic under investigation. In order to ensure the robustness and reliability of the dataset, the search strategy deliberately focused on articles written in the English language, thereby facilitating access to a broad and diverse spectrum of internationally relevant works that have contributed significantly to the existing body of knowledge. Following the removal of duplicate titles and a rigorous screening process to eliminate publications that were extraneous to the theme under investigation, a total of 81 pertinent documents were meticulously selected, exported in CSV format, and subsequently subjected to thorough analysis. This fastidious selection process, as illustrated in Figure 1, was carefully designed to adhere to established best practices in bibliometric research (Wong et al., 2020; Nyakuma et al., 2023; Amponsah et al., 2025), as well as the PRISMA guidelines (Page et al., 2021). This is to ensure the transparency, rigor, and reproducibility of the study's findings

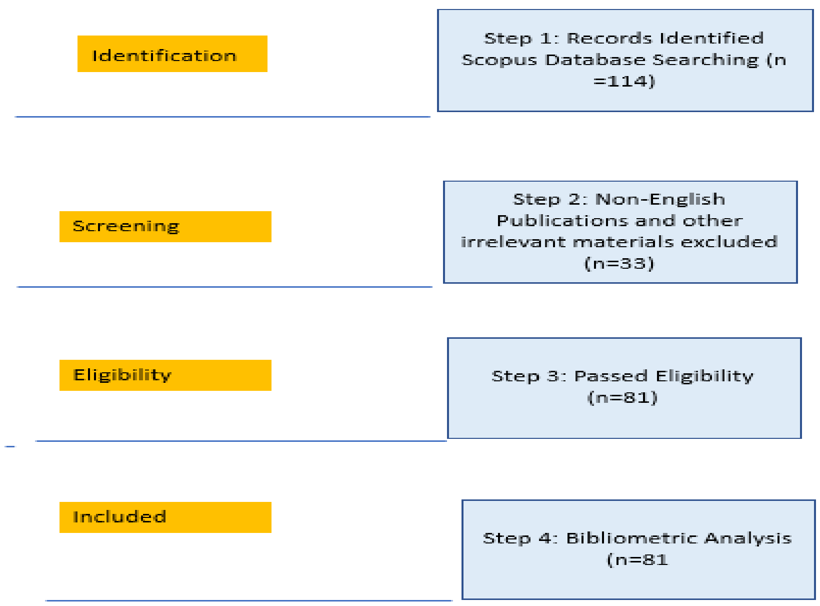

Figure 1: The Process of Articles' Selection

The final dataset comprised comprehensive metadata, which were then analyzed, leveraging Excel software, and using a range of bibliometric metrics, such as publication count and citation analysis, to assess the productivity and impact of authors, organizations, and countries in the field of ERM. Furthermore, the VosViewer software was employed to perform social network analysis, thereby visualizing the complex relationships between countries, organizations, and authors, as well as keyword co-occurrence analysis (KCA), which offered valuable insights into the thematic structure and knowledge domains underlying the research field. The resulting maps and visualizations illustrated intricate networks of nodes and lines, representing publication weights and collaborative relationships, and offered a nuanced understanding of the dynamics driving research in this area. The node sizes corresponded to the publication weight, indicating the relative importance or productivity of each node. Meanwhile, the line widths represented the strength of collaboration between nodes, measured by the number of co-authored publications. Additionally, VosViewer facilitated KCA, which mapped the relationships between keywords extracted from the selected publications, providing insights into thematic patterns and knowledge structures within the research field.

3. Result and Discussion

3.1 General Publication and Citation Trends

As evident in Figure 2, all the 81 studies relating to ERM, published in Scopus-indexed sources, were published between 1992 and 2025. The works produced by Littleboy et al. (1992a), titled 'Impact of soil erosion on production in cropping systems. I. development and validation of a simulation model', and Littleboy et al. (1992b), titled 'Impact of soil erosion on production in cropping systems. II.* Simulation of production and erosion risks for a wheat cropping system is the first set of works relating to ERM that is indexed in Scopus. Both studies were published in the Australian Journal of Soil Research. Ever since 1992, when the pioneering works were published in Scopus-indexed sources, a lull in ERM-based research was observed from a period spanning 1993-1997, as there was no publication related to ERM recorded for the epoch. Similar zero presence of ERM-based works in the Scopus database was observed from 1999-2001, 2005-2006, and in 2017. While the years 1998, 2004, 2007, 2008, 2010, 2011, 2012, and 2013 recorded the lowest number of publications at one each, the year 2024 recorded the highest number of publications at 20. From 2020 to 2022, a doubling of ERM-related publications manifested from 4 to 8. This spike, however, plunged to 5 in 2023 before an eventual peaking in 2024. As of the point at which the data was extracted from Scopus, about 13 publications have been recorded for the year 2025. The dynamics of ERM-related publications, over the years, may be borne out of increased awareness of climate change impacts, post COVID-19 (Ngo et al., 2025), as researchers are now increasingly focusing on mapping and mitigating climate-related risks. Similarly, the advent of new methodologies such as remote sensing and GIS-based models and the increasing mastery of the techniques have improved the accuracy and efficiency of erosion risk assessments (Zhao et al., 2024; Al-hasn et al., 2024; Wang 2025), thereby enabling more interests and active investments in the application of the techniques to mapping erosion risks and creating spatial contexts for mitigation measures.

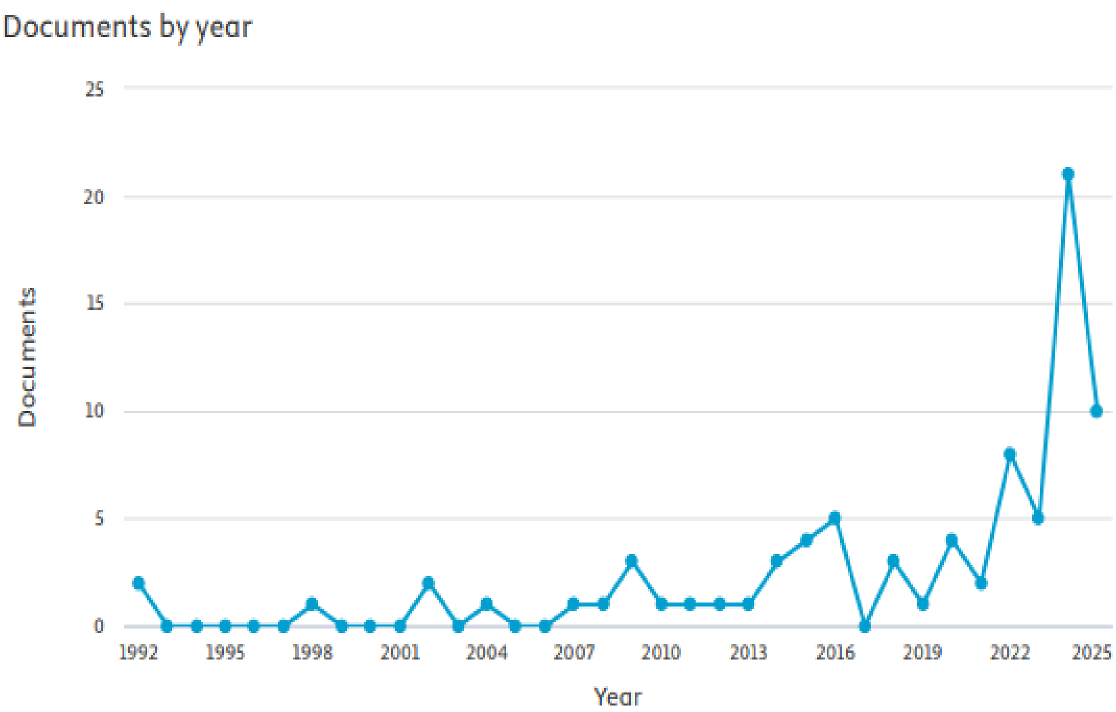

Figure 2: Temporal changes in the number of ERM-related publications

Analysis, as shown in Figure 3, reveals that the majority (84%) of the 81 published ERM research documents indexed in the Scopus database are made up of articles. This is followed by conference publications (7.4%), book chapters (4.9%), reviews (2.5%), and letters (1.2%).

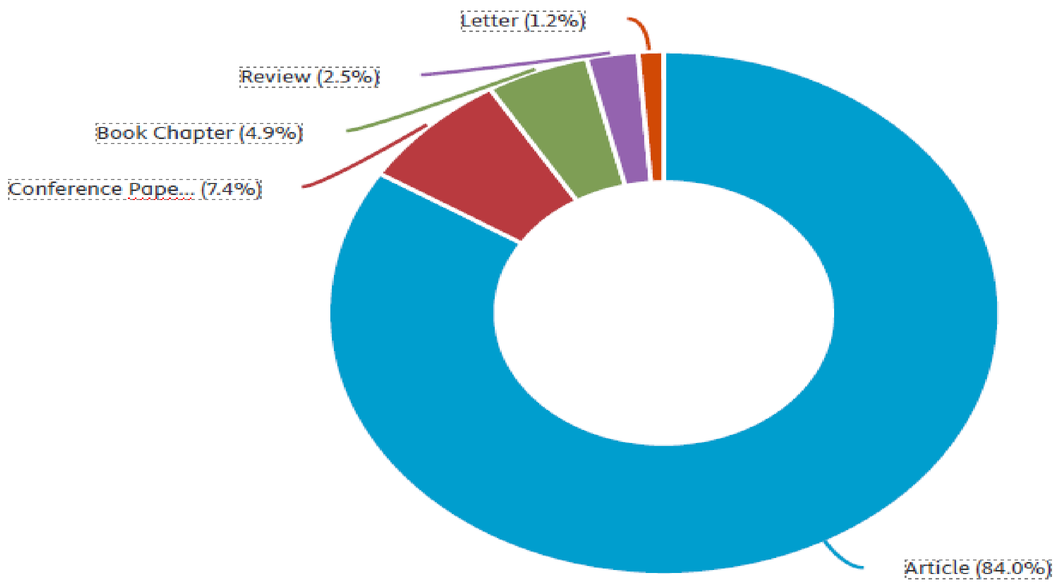

Figure 3: Publication Type

Moreover, as displayed in Figure 4, ERM-related articles published circa 1992, being the pioneering works indexed in Scopus, accounted for about 213 cumulative citations. This count of ERM-related articles plunged to 3 in the year 2007, peaked at 405 in the year 2009, and then plunged to the lowest count of 2 in the year 2025. The observation in respect of the high citations of ERM-related articles published in Scopus-indexed sources in the years 1992 and 2009 is significantly accounted for by the seminal nature of two articles: 'Impact of soil erosion on production in cropping systems. I. development and validation of a simulation model' by Littleboy et al. (1992a), which has about 179 citations, and 'soil erosion prediction in the Grande River Basin, Brazil using distributed modelling by Beskow et al (2009), which has about 246 citations.

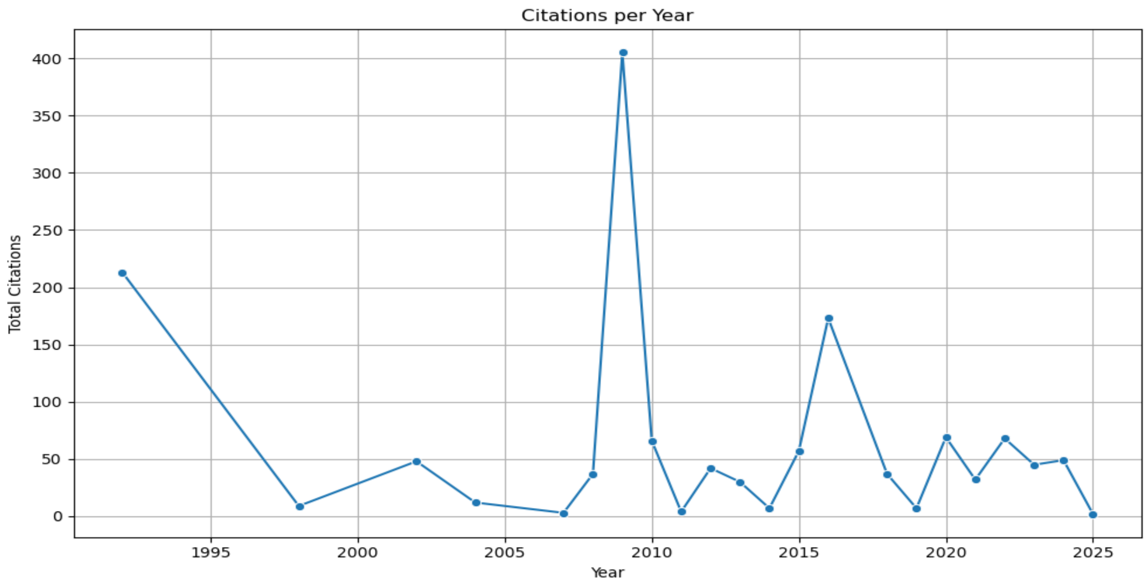

Figure 4: The number of citations received related to ERM

3.2 Top-Cited Publications and Journals in ERM Research Landscape

A mean value of 17.5 was recorded as the per-unit publication citation number for studies relating to ERM. This is probably borne out of the fledgling nature of the research, as techniques and procedures required for ERM studies that can compete in the high-impact publications terrain are complex, and their mastery is limited to a few academics and professionals in the environmental sphere of knowledge. However, information in Table 1 reveals the top-cited ERM-based research in the Scopus database.

Table 1. Top-cited Publications in GS Research, Total Citations, and Affiliated Countries.

Title	Total Citations	Sources	Affiliations of Corresponding Author
Soil erosion prediction in the Grande River Basin, Brazil, using distributed modelling, Beskow et al. (2009)	246	Catena	National Soil Erosion Research Laboratory, Purdue University, United States, and Department of Agricultural Engineering, Federal University of Lavras, Brazil.
Impact of soil erosion on production in cropping systems. I. development and validation of a simulation model, Littleboy et al. (1992a)	179	Australian Journal of Soil Research	Land Management Research Branch, Queensland Department of Primary Industries, Indooroopilly, Australia.
Erosion risk assessment of active coastal cliffs in temperate environments, Del Río & Gracia (2009)	96	Geomorphology	Earth Sciences Department, CASEM, University of Cádiz. Cádiz, Av. Republica Saharaui Puerto Real, Spain
Estimation of soil erosion using USLE and GIS in Awassa Catchment, Rift Valley,	80	Geoderma Regional	Department of Geology, Aligarh Muslim University, Aligarh, India.

Central Ethiopia, Ali & Hagos (2016).			
Identification of priority areas for controlling soil erosion, Zhang et al. (2010)	66	Catena	Institute of Remote Sensing Applications, Chinese Academy of Sciences, Beijing, China
Integrated tool for risk assessment in agricultural management of soil erosion and losses of phosphorus and nitrogen, Bechmann et al. (2009)	63	Science of the Total Environment	Bioforsk, Norwegian Institute for Agricultural and Environmental Research, N-1432 Aas, Frederik A. Dahls vei 20, Norway
Assessment of the cover changes and the soil loss potential in European forestland: First approach to derive indicators to capture the ecological impacts on soil-related forest ecosystems, Borrelli et al. (2016)	48	Ecological Indicators	European Commission, Joint Research Centre, Institute for Environment and Sustainability, Ispra, Italy;
Integration of GIS and remote sensing for estimation of soil loss and prioritization of critical sub-catchments: A case	42	Natural Hazards	Department of Geosciences, Federal University of Paraíba, João Pessoa, Brazil

study of Tapacurá catchment, da Silva et al. (2012)			
Study on the spatial pattern of rainfall erosivity based on geostatistics in Hebei Province, China, Men et al. (2008)	37	Frontiers of Agriculture in China	College of Resources and Environmental Sciences, Agricultural University of Hebei, Baoding, China.
Assessment of land management practices on soil erosion using the SWAT model in a Tunisian semi-arid catchment, Mosbahi & Benabdallah (2020)	36	Journal of Soils and Sediments	Higher School of Agriculture, Mograne, Zaghouan, 1121, Tunisia; Center for Water Research and Technologies, Soliman, Tunisia

Mosbahi & Benabdallah (2020)'s work, which utilised the SWAT model to predict soil erosion over the catchment of the Sarrath River located in Tunisia, and equally assessed the efficacy of various erosion risk management practices, has a total citation count of 36. Men et al. (2008) focused on assessing the spatial pattern of rainfall erosivity based on geostatistics in Hebei Province, China, to provide maps that can assist soil and water management policy and planning endeavours. It has a citation count of 37. Da Silva et al. (2012), which integrated advanced techniques of GIS and remote sensing in assessing soil erosion and prioritization of Tapacurá catchment, has a total citation count of 42. Furthermore, Borrelli et al. (2016), who conducted the first pan-European spatial delineation of forest cover dynamics in 36 European countries, have a total count of 48. Bechmann et al. (2009), with a total citation count of 63, proposed the development of an integrated risk evaluation tool in the management of soil loss and important chemicals like phosphorus and nitrogen. Zhang et al. (2010), with a total citation count of 66, identified priority areas for managing soil erosion, deploying specific multicriteria assessment approaches. Moreover, Ali & Hagos (2016), who estimated soil erosion in the Catchment of Awassa in Central Ethiopia, deploying Universal Soil Loss Equation (USLE) and GIS, have up to 80 citations. Del Río & Gracia (2009), having a total citation count of 96, deployed a novel practical method to assess cliff erosion risk in temperate environments. This was achieved through the analysis of the main physical and socioeconomic variables accounting for erosion. Similarly, Littleboy et al. (1992a) deployed a computer simulation model known as PERFECT to assess risks of soil erosion to the long-term production of crops. However, Beskow et al. (2009), who applied USLE with GIS PCRaster in order to assess potential soil erosion from the upstream of Grande River Basin, enabling the mapping of susceptible areas to water erosion, have the highest citation count of 246. It is worth noting that all the top-cited works are empirical articles. None of the works are premised on systematic review techniques like bibliometric analysis that usually command a high level of citations (Montori et al., 2003). This, as a matter of fact, is one of the factors that make this bibliometric study highly imperative.

Moreover, as evident in Figure 5, the top of the 10 journals that have featured ERM research is Catena with 312 citation count. This is followed by Australian Journal of Soil Research (213), Geomorphology (96), Geoderma Regional (80), Science of the Total Environment (63), Natural Hazards (59), Land Degradation and Development (48), Ecological Indicators (48), Journal of Environmental Management (44), and Frontiers of Agriculture in China (37). The dominance of the Australian Journal of Soil Research and Catena concerning citations in the community of journals is borne out of the fact that leading works such as Littleboy et al. (1992a), which has about 179 citations, and Beskow et al (2009), which has about 246 citations, were published in the journals, respectively.

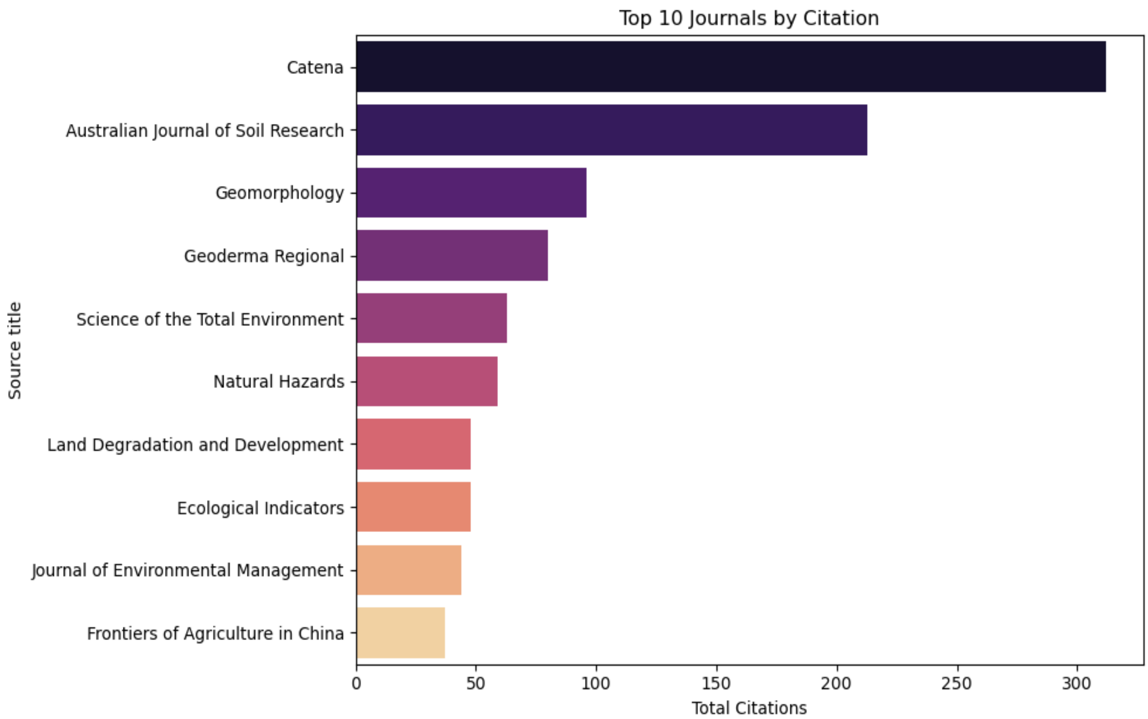

Figure 5: Top-10 Journals That Have Featured ERM Research by Citations

3.3 Funding Agencies, Organizations, and Countries' Representation in ERM research

It is imperative to examine financial support sources for GS research. This is owing to how funding is key to the viability and seamlessness of research. Foremost, it is relevant to mention that a total of 112 funding organizations are associated with the 81 works connected with ERM. However, as presented in Table 2, of the 112 funding organizations, only the United Kingdom's Natural Environment Research Council had supported up to 3 ERM-related research projects. Similarly, the Ministry of Education and Science of the Republic of Kazakhstan, Conselho Nacional de Desenvolvimento Científico e Tecnológico, CNPQ, and the National Institute of Food and Agriculture, NIFA, have each financially supported two ERM-related works. The remaining 108 have each supported one ERM-connected research. It is noteworthy to mention that Africa was represented by the Ethiopian Government and Debre Markos University, DMU, Ethiopia, in the list of funding agencies that have financed ERM-based studies. The fact that 79.46% of the publications were published post-COVID-19 could be explained by Ngo et al. (2025)'s finding with respect to the increased organisational awareness of the impacts of climate change that was occasioned by COVID-19.

Table 2. Number of Publications per Project from 10 Top Funding Agencies

Number Of Publications	Year	Funding Agencies
2	2025	Ministry of Education and Science of the Republic of Kazakhstan
2	2024	Conselho Nacional de Desenvolvimento Científico e Tecnológico, CNPQ, Brasil.
3	2025	Natural Environment Research Council, NERC, United Kingdom
2	2024	National Institute of Food and Agriculture, NIFA, USA.
1	2023	NCN National Science Centre, Poland
1	2023	Deutscher Akademischer Austauschdienst, DAAD, Germany

1	2023	Ethiopian Government
1	2024	State Forest Resources Agency of Ukraine
1	2022	Debre Markos University, DMU, Ethiopia
1	2024	Chinese Academy of Sciences, CAS

Moreover, it is pertinent to mention that the Environment Agency, Bristol, with about 3 publications, emerged as the institution where the most ERM works are associated. As presented in Table 3, this is followed by organizations such as Newcastle University, Ankara University, Polish Academy of Science, University of Lavras (UFLA), University of Science and Technology Beijing, Technische Universität Dresden, TUD, Canakkale Onsekiz Mart University, Consiglio Nazionale Delle Ricerche, and Niigata University, each with 2 publications.

Table 3. 10 Top Institutions That are Affiliated with Erosion Management Researches

Institutions	Number of Publications	Countries
Environment Agency, Bristol	3	UK
Newcastle University	2	UK
Ankara University	2	Turkey
Polish Academy of Science	2	Poland
University of Lavras (UFLA)	2	Brazil
University of Science and Technology Beijing	2	China

Technische Universität Dresden, TUD	2	Germany
Canakkale Onsekiz Mart University	2	Turkey
Consiglio Nazionale Delle Ricerche	2	Italy
Niigata University	2	Japan

When estimated aggregately, Indian institutions account for the most ERM-related research. These, as presented in Figure 6, are followed by German, British, Italian, American, Australian, Chinese, Ethiopian, Japanese, and Spanish organisations, respectively. The dominance of European countries in the list of the 10 top organizations and funding agencies that are affiliated with ERM research endeavours represents a challenge for organizations and funding agencies in developing economies of Africa and Asia that are yet to evolve adequate resilience measures for grappling with erosion risks, where there are vistas and great opportunities for ERM-based research.

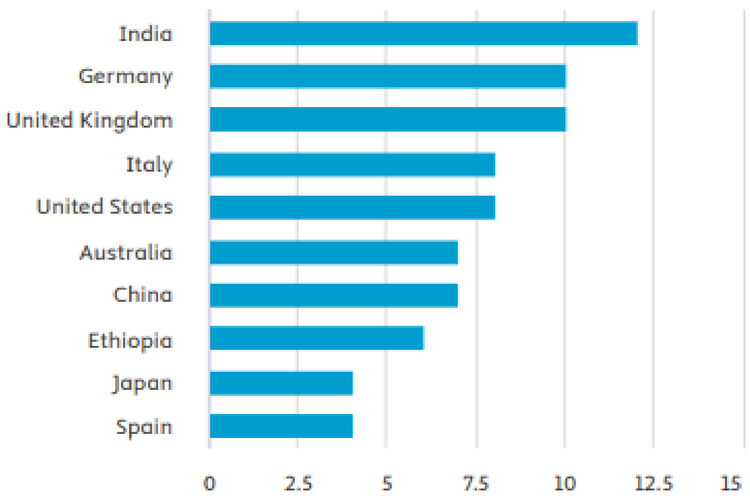

Figure 6: **Countries' Representation in ERM research.**

3.4 Productivity and collaboration network

Figure 7 depicts the extent of collaboration among the most prolific countries in ERM research, as evidenced by co-authorship networks. The collaboration patterns among countries clearly show that countries like Japan and Spain do not have significant international collaboration in ERM research. Hence, they are not represented in the network visualization map. In contrast, the United States stands out with a total link strength (TLS) of 5, indicating strong collaborative ties with other countries that are represented in ERM research. It is ahead of Germany, China, Italy, the United Kingdom, Australia, Ethiopia, and India with TLS of 4,3,3,3,2,2,2, respectively. As evident in the map depicted in Figure 7, ERM-minded researchers in the United States have collaborated with counterparts from Italy, Australia, Germany, and China. This is just like ERM-minded researchers in Germany who have collaborated with their counterparts in the United States, Australia, Italy, and Ethiopia. Researchers from the other 6 countries on the map have only collaborated with their counterparts in two countries.

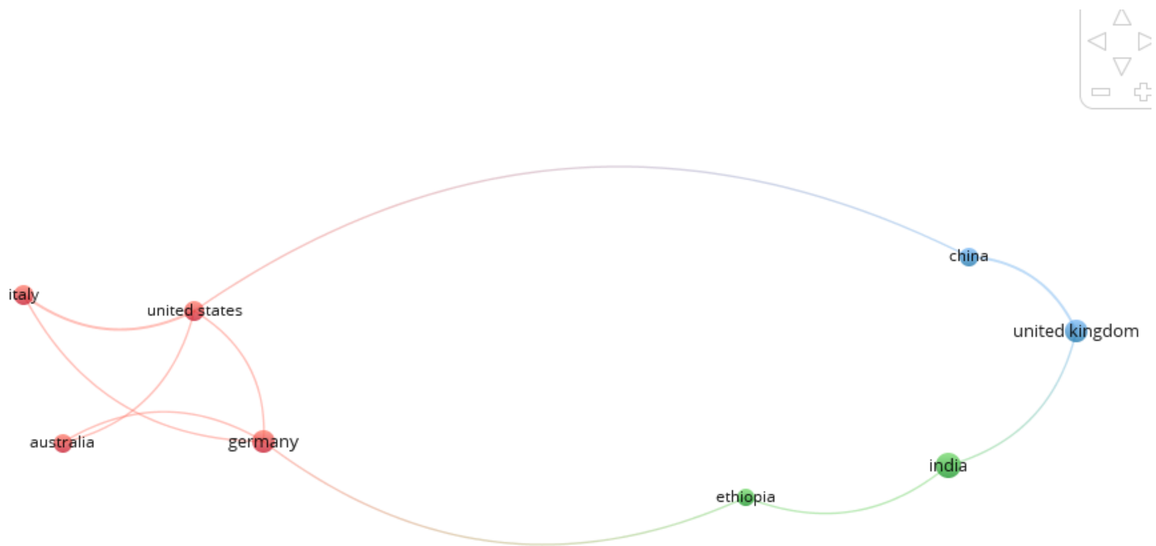

Figure 7: Network visualization map for country-level co-authorship

Similarly, of all the 226 organizations affiliated with ERM research, only 9 have collaborated in a minimum of 2 publications. As depicted in Table 4, the 6 top collaborating organizations, sharing a TLS of 10, are Department of Cartography and Geoinformatics, Faculty of Geography and Environmental Sciences, Al-Farabi Kazakh National University, Kazakhstan; Department of Geography, Land Management, and Cadastre, Faculty of Geography and Environmental Sciences, Al-Farabi Kazakh National University, Kazakhstan; Graduate School of Science and Technology, Niigata University, Niigata, Japan; School of Applied Computational Sciences, Meharry Medical College, Nashville, United States; School of Civil, Environmental and Land Management Engineering, Politecnico Di Milano, Italy; and Space Technologies, and Remote Sensing Center, Al-Farabi Kazakh National University, Kazakhstan. However, these are followed by other organizations, which share similar TLS of 4, like the Department of Applied Mathematics, University of Science and Technology Beijing, China; Environmental Change Institute, Oxford University Centre for the Environment, University of Oxford, United Kingdom; and School of Civil Engineering and Geosciences, Tyndall Centre for Climate Change Research, Newcastle University, United Kingdom.

Table 4. Co-authorship at the Organization Level (Minimum number of 2 Publications per Organization)

S/N	Organization	Number of Publications	Citations	Total Link Strengths
1	Department of Cartography and Geoinformatics, Faculty of Geography and Environmental Sciences, Al-Farabi Kazakh National University, Kazakhstan	2	1	10
2	Department of Geography, Land Management, and Cadastre, Faculty of Geography and Environmental Sciences, Al-Farabi Kazakh National University, Kazakhstan	2	1	10
3	Graduate School of	2	1	10

	Science and Technology, Niigata University, Niigata, Japan.			
4	School of Applied Computational Sciences, Meharry Medical College, Nashville, United States.	2	1	10
5	School of Civil, Environmental and Land Management Engineering, Politecnico Di Milano, Italy.	2	1	10
6	Space Technologies and Remote Sensing Center, Al-Farabi Kazakh National University, Kazakhstan.	2	1	10
7	Department of Applied Mathematics, University of Science and Technology Beijing, China.	2	1	4
8	Environmental Change Institute, Oxford University Centre for the Environment,	2	1	4

	University of Oxford, United Kingdom.			
9	School of Civil Engineering and Geosciences, Tyndall Centre for Climate Change Research, Newcastle University, United Kingdom	2	1	4

As shown in the network visualization map for co-authorship at the organization level, depicted in Figure 9, the six schools that have mutually collaborated in ERM research exist in a single cluster. The organizations are: Department of Cartography and Geoinformatics, Faculty of Geography and Environmental Sciences, Al-Farabi Kazakh National University, Kazakhstan; Department of Geography, Land Management, and Cadastre, Faculty of Geography and Environmental Sciences, Al-Farabi Kazakh National University, Kazakhstan; Graduate School of Science and Technology, Niigata University, Niigata, Japan; School of Applied Computational Sciences, Meharry Medical College, Nashville, United States; School of Civil, Environmental and Land Management Engineering, Politecnico Di Milano, Italy; and Space Technologies, and Remote Sensing Center, Al-Farabi Kazakh National University, Kazakhstan. These six organizations are also the ones with the highest TLS value of 10.

Figure 8: Network visualization map for co-authorship at the organization level (minimum number of 2 publications per organization)

Furthermore, it is pertinent to state that about 331 authors have contributed to ERM research. However, of the 331 authors, only 21 authors, representing about 6.34%, have published more than 1 publication relating to ERM. The top ten most cited of the 21 are presented in Figure 9. While the ERM-related works associated with the triad of leading researchers, Avanzi J.C., Curi N., and Viola M.R., share a citation count of 247, Norton L.D., Beskow S., and Mello C.R. are associated with ERM-related works that each share a cumulative citation count of 246. These are followed by Freebaim D.M., Hammer G.L., and Littleboy M, whose ERM-related works each share a citation count of 213. Moreover, Woodruff D.R. is associated with work with the least citation count of 179.

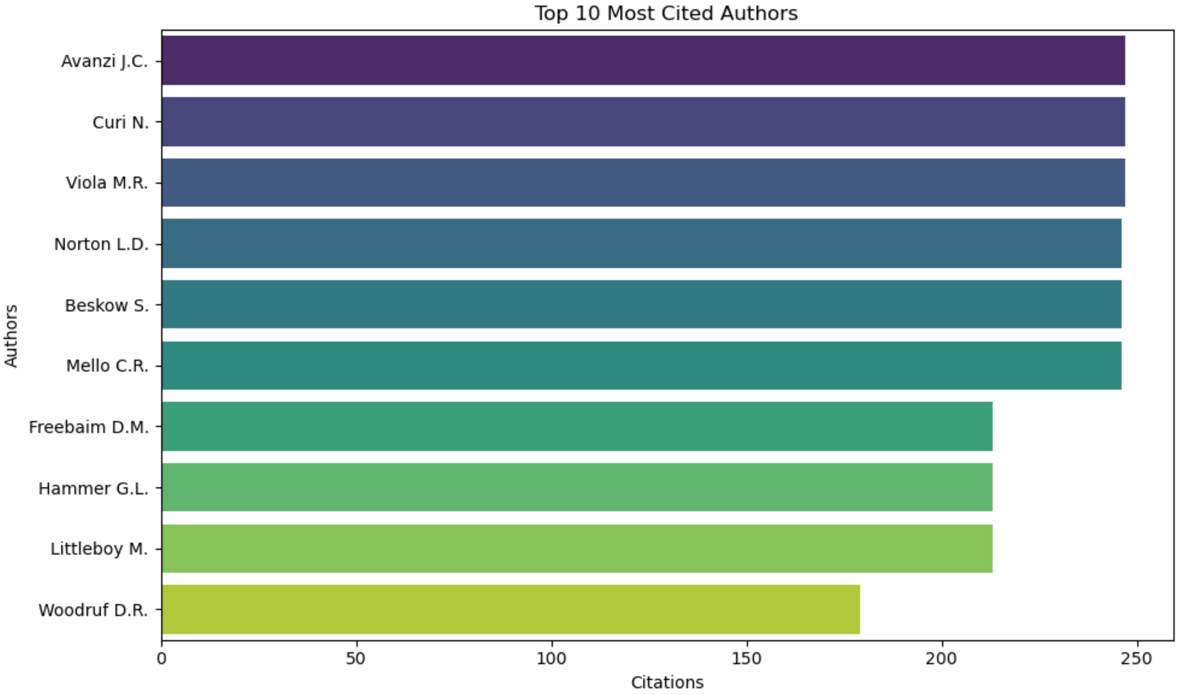

Figure 9: Top-ten Widely Published Researchers in ERM-Related Research

Moreover, the co-authorship network is well-mapped in the figure. 10. All eight authors identified within the single cluster of the map are mutually connected. The authors are Damira K., Aigul T., Omirzhan T., Kanat Z., Moldir R., Moldir S., Eugene L., and Nail B.

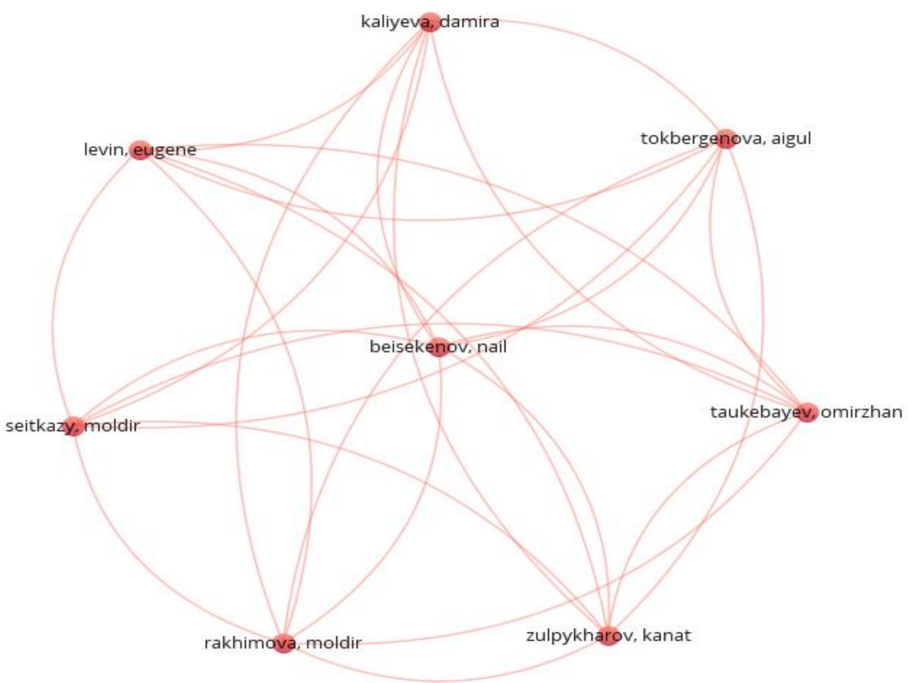

Figure 10: Visualization map for co-authorship networks

3.5 Keywords Co-occurrence Analysis (KCA)

KCA has been used in various studies (Nyakuma et al. 2021; Nadi-Ravandi & Batooli 2022; Zhao 2022) to explore the underlying concepts, current focus, patterns, and emerging trends in different areas of knowledge. Similarly, KCA represents an important aspect of bibliometric analysis conducted to highlight the most dominant concepts that represent the focus of research (She et al., 2022; Zhang et al., 2021). In the context of ERM, the KCA conducted with the aid of VOSviewer, reveals the occurrence of 848 keywords. But out of the 848, only 34 complied with the minimum threshold of 4 occurrences. The network visualization map (Figure 11) shows four clusters represented by differently-sized coloured nodes. The different coloured nodes indicate a research hotspot or theme related to the topic. However, the sizes of the node point to the frequency of occurrence or importance to the area of knowledge, to the sphere of research.

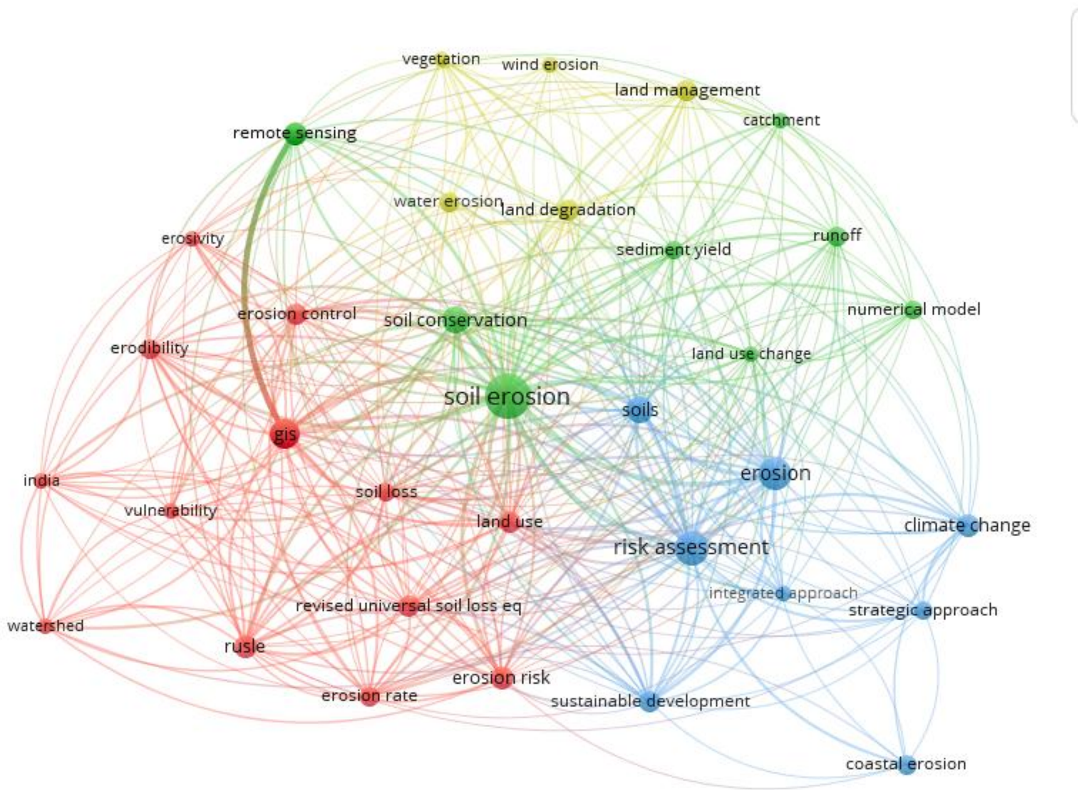

Fig. 11. Network visualisation map of Keyword Co-occurrence for GS-related Research

The 34 top keywords have been identified and grouped into 4 clusters, with their occurrences and TLS well indicated in Table 5. Cluster 1, coloured red, made up of 13 items such as erodibility, erosion control, erosion rate, erosion risk, erosivity, GIS, India, land use, Revised Soil Loss

Equation, RUSLE, soil loss, vulnerability, and watershed, is broadly classified as soil erosion and modelling techniques. Further, cluster 2, coloured green, comprising 8 items such as catchment, landuse change, numerical model, remote sensing, runoff, sediment yield, soil conservation, and soil erosion, is broadly classified as Watershed Management and Soil Erosion Studies. Similarly, cluster 3 (blue), consisting of 8 items like climate change, coastal erosion, erosion, integrated approach, risk assessment, soil, strategic approach, and sustainable development, is broadly classified as erosion assessment and sustainability studies. However, cluster 4, coloured yellow, encapsulating five items such as land degradation, land management, vegetation, water erosion, and wind erosion, is classified as erosion and land degradation management.

Table 5: Clusters, Keywords, Occurrences, and Total Link Strengths

Number	Keywords	Occurrences	Total Link Strength (TLS)
Cluster 1(Red)			
1	Erodibility	7	54
2	Erosion Control	7	46
3	Erosion rate	7	46
4	Erosion risk	10	51
5	Erosivity	5	28
6	GIS	14	90
7	India	5	32
8	Land use	8	66
9	Revised Universal Soil Loss Equation	8	59
10	Rusle	10	66
11	Soil loss	6	48
12	Vulnerability	5	34
13	Water Shed	5	32

Cluster 2 (Green)			
14	Catchment	5	21
15	Land use change	5	42
16	Numerical model	6	29
17	Remote sensing	7	39
18	Runoff	7	35
19	Sediment yield	6	41
20	Soil conservation	14	97
21	Soil erosion	37	186
Cluster 3 (Blue)			
22	Climate Change	10	32
23	Coastal Erosion	7	12
24	Erosion	20	97
25	Integrated approach	5	26
26	Risk assessment	22	101
27	Soils	13	83
28	Strategic approach	6	22
29	Sustainable development	8	54
Cluster 4 (Yellow)			
30	Land Degradation	8	36
31	Land	8	31

	Management		
32	Vegetation	5	21
33	Water Erosion	7	23
34	Wind Erosion	5	14

The KCA offers the premises for understanding existing trends and underestimated dimensions of ERM. For instance, it is evident from Table 5 that soil erosion, risk assessment, soil conservation, erosion, and GIS, with values of 186, 101, 97, 97, and 90, respectively, account for the highest TLSs. This suggests that ERM research has been dominated by erosion risk assessment, which has leveraged increased understanding of GIS techniques. While it is commendable that GIS is being deployed for erosion risk assessment, machine learning and deep learning algorithms, which offer even smarter, cheaper, and more efficient means of assessing erosion risks (Ganasri & Ramesh 2016; Gholami et al., 2021; Ghaith & Li, 2020; Khosravi *et al.,* 2023) are yet to be optimally exploited as predictive models for analysing and mapping the different dimensions of erosion risks. Moreover, most of the ERM works have focused on the physical dimension of erosion vulnerability. None of the studies has leveraged several theoretical frameworks for vulnerability assessment (Ali et al., 2024; Moreira et al., 2021) in the adoption of an index-based approach to comprehensively assess erosion vulnerability along physical, social, economic, and environmental factors, and aggregating relevant indicators of the erosion risk, such as exposure, susceptibility, and resilience under each factor. This brings to the fore the need for erosion risk vulnerability assessment as a management measure required as an adaptation strategy for grappling with and resolving potential impacts, adapting the thrusts of numerous studies undertaken to interrogate the concept of flood vulnerability (Nasiri & Shahmohammadi-kalalagh, 2013; Hudso et al., 2018; Ibrahim et al., 2021; Moreira et al., 2021; UNESCO-IHE, 2023). Vulnerability assessment is the measure of exposure, sensitivity, and resilience of socio-ecological systems to a specific hazard (He et al*.,* 2021; Maharjan et al., 2024). Similarly, none of the existing sundry erosion modelling endeavors has deployed the Structural Equation Modelling (SEM) to assess more intricate relationships between the erosion vulnerability constructs and indicators. Based on the KCA, it is evident that the emphasis of current works has generally focused on soil erosion, with water and wind erosion mentioned separately. However, other types of erosion, like gully erosion, rill erosion, or tillage erosion, are not prominent in existing studies. Similarly, there is insufficient emphasis on mitigation strategies. While erosion control and soil conservation are mentioned severally in existing ERM-related studies, specific strategies like agroforestry, terracing, or cover cropping are not highlighted. It is also observed that ERM studies by African authors, funded by African funding agencies to assess African land degradation challenges, are grossly underrepresented in existing ERM research endeavours. These gaps are observable from KCA and suggest opportunities for further research and policy development in ERM research.

3.6 Research Gaps and Future Directions for Research

Sundry works have generated new knowledge in the field of ERM. Yet systematic assessments of the milestones achieved in the works, trends, and patterns that leverage the bibliometric technique are limited. However, this work has employed a bibliometric method to offer a broad assessment of global research trajectories, making it possible to identify influential authors, leading publications, and institutions in the field of ERM. The work has also explored the hitherto underexplored network analysis and keyword co-occurrence examination to uncover hidden patterns and trends in the existing body of knowledge, revealing under-explored areas and emerging trends. For instance, the key fundamental research categories mapped under KCA are soil erosion and modelling techniques, watershed management and soil erosion studies, erosion assessment and sustainability studies, and erosion and land degradation management. Yet, the bibliometric analysis reveals further gaps in ERM research that afford the vista of potential research avenues for future research agendas. First, analysis reveals that there are opportunities in the deployment of predictive models that leverage machine learning or deep learning to enhance the scalability and accuracy of erosion risk assessment. Second, index-based approaches can be adopted to standardize erosion vulnerability assessment across diverse geographical and conceptual contexts. Third, complex relationships between the different factors of erosion vulnerability can be studied through the deployment of Structural Equation Modelling (SEM). Fourth, there is a need to prioritize under-researched contexts, particularly African countries with limited mechanisms of resilience, where erosion impacts are severe but scholarly attention is inadequate. Fifth, there is a vista for mainstreaming practical mitigation approaches within ERM frameworks to bridge the gap between research and action.

4. Conclusion

This study conducted a comprehensive examination of the research landscape of ERM based on 81 publications indexed in the Scopus database from 1992 to 2025. Analyses revealed that there is an increased productivity in ERM research post-COVID-19, which was attributed to increased awareness of climate change impacts, post-COVID-19, and deepened knowledge of new methodologies such as remote sensing and GIS-based models. Funding for ERM research is limited to 112 funding organizations, with the United Kingdom's Natural Environment Research Council supporting up to 3 ERM-related projects, and the Environment Agency, Bristol, associated with the most ERM studies. Furthermore, it is pertinent to state that about 331 authors have contributed to ERM research. However, of the 331 authors, only 21 authors, representing about 6.34%, have published more than 1 publication relating to ERM. While the ERM-related works associated with the triad of leading researchers, Avanzi J.C., Curi N., and Viola M.R., share a citation count of 247. Author productivity analysis shows that the triad of Avanzi J.C., Curi N., and Viola M.R. has the most impactful research based on citation counts, with Catena having the reputation of the most cited journal when it comes to ERM research. When estimated aggregately, Indian institutions account for the most ERM-related research. Moreover, KCA reveals four major research hotspots broadly classified as soil erosion and modelling techniques, watershed management and soil erosion studies, erosion assessment and sustainability studies, and erosion and land degradation management. However, the analysis also revealed existential gaps in the current research landscape, suggesting that future studies should focus on: developing predictive models using machine learning or deep learning techniques to assess erosion risks, adopting an index-based approach for erosion vulnerability assessment, and deploying the Structural Equation Modelling (SEM) to assess the more intricate relationships between the erosion vulnerability constructs and indicators. Moreover, the future research agenda should centre on exploring under-researched contexts of erosion problems in African countries that currently have low resilience mechanisms, and the need to mainstream more mitigation strategies in ERM.

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