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BIBLIOMETRIC ANALYSIS OF SOIL POLLUTION RESEARCH BASED ON WEB OF SCIENCE

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Abstract

This study analyzed 5,166 research and review articles on the topic of soil pollution published up to July 20, 2024, including 72 top-cited papers. The publications, primarily written in English, originated from 129 countries or regions and appeared in 961 journals and five book series. The five most productive journals were Science of the Total Environment (298 articles, 5.77%), Environmental Science and Pollution Research (218, 4.22%), Environmental Pollution (162, 3.14%), Chemosphere (142, 2.75%), and Environmental Monitoring and Assessment (138, 2.67%). The top five contributing countries - China, Spain, the United States, Poland, and India - each published more than 275 papers. Using co-occurrence network visualization with VOSviewer, the keywords were grouped into seven distinct thematic clusters. In addition, the 25 keywords with the strongest citation bursts were identified through CiteSpace analysis. Most of the publications were aligned with three key Sustainable Development Goals: Sustainable Cities and Communities (SDG 11), Zero Hunger (SDG 2), and Climate Action (SDG 13). The findings of this study not only provide a comprehensive overview of the current state of research in soil pollution but also offer valuable guidance for shaping future research directions in this critical environmental field.

Key words: *bibliometric analysis, soil pollution, VOSviewer, CiteSpace, Web of Science.*

INTRODUCTION

Soil, as one of the most fundamental natural resources for human survival, is increasingly threatened by various types of pollutants. Among these, environmental pollution caused by agricultural mulch film residues has become a growing concern, attracting significant research attention in recent years (Wang et al., 2024). Bibliometric analysis has provided valuable insights into the research landscape, trends, and thematic domains within the field of soil micro- and nanoplastics pollution (Liu et al., 2023).

Gao et al. (2022) conducted a comprehensive literature review on the subject of "land pollution" using CiteSpace software, performing both bibliometric analysis and visual presentation. Similarly, Pan et al. (2024) analyzed global trends and the evolution of research hotspots in soil microplastic pollution. Gong et al. (2023) conducted a bibliometric study on global research activities related to micro- and nanoplastic toxicity in earthworms.

Another emerging area of concern is military-related soil pollution, where heavy metal contamination remains the primary issue, as highlighted by Stadler et al. (2022). Du et al. (2022) reviewed influencing factors, threshold derivation, and the application of heavy metal limits in soils using a combined approach of bibliometric analysis and scientific knowledge mapping. Gao et al. (2022) also applied bibliometric techniques to evaluate global research efforts in soil remediation. In a related context, Ajibade et al. (2022) found that incorporating biochar and compost into soils can reduce pollutant uptake by plants and improve soil nutrient content and productivity. As research on soil health has expanded, Liu et al. (2020) performed a bibliometric analysis of publications on soil health from 1999 to 2018. Furthermore, Sun and Yuan (2023) analyzed top-cited papers in the field of soil science, while Yuan and Sun (2023) investigated research trends related to rice and greenhouse gas emissions.

The purpose of the present study is to conduct a bibliometric analysis of global research

output on the topic of "Soil Pollution" using the Web of Science (WoS) Core Collection from Clarivate Analytics. The analysis was carried out using CiteSpace and VOSviewer software to map trends, hotspots, and knowledge structures in the field.

MATERIALS AND METHODS

1. Web of Science

The publication data were retrieved from the Web of Science Core Collection, specifically from the following indexes: the Science Citation Index Expanded (SCIE, 1900–present) and the Social Science Citation Index (SSCI, 2005–present). Additionally, records were collected from the Conference Proceedings Citation Index–Science (CPCI-S, 2015–present) and the Conference Proceedings Citation Index–Social Science & Humanities (CPCI-SSH, 2015–present).

2. Data collection

Data collection was completed on July 20, 2024. The search was conducted using the following topic (TS) keywords: "Soil Pollution", "Agricultural Soil Pollution", "Soil Pollution Assessment", "Soil Pollution Control", "Urban Soil Pollution", and "Water and Soil Pollution". Only documents categorized as articles or review articles were included.

In total, 5,166 records were obtained from the WoS Core Collection. Journal impact factors (both IF 2023 and 5-year IF) were obtained from the *Journal Citation Reports* (JCR 2023), published in June 2024, which contained the most recent available data.

3. VOSviewer and CiteSpace

For bibliometric visualization, VOSviewer version 1.6.20 (van Eck & Waltman, 2023) was used with its default parameter settings. The top 25 keywords with the strongest citation bursts were identified and analyzed using CiteSpace (Basic version 6.3.R1).

RESULTS AND DISCUSSIONS

1. Document type and language of publication

All 5,166 publications analyzed in this study were indexed in the following databases: SCIE (5,111 papers, 98.94%), SSCI (307, 9.94%), CPCI-S (190, 3.68%), and CPCI-SSH (231, 5.83%). Regarding document type, the majority were research articles (4,776 papers, 92.45%), followed by review articles (390 papers, 7.55%) and proceedings papers (190 papers, 3.68%). Most papers were published in English (5,015 papers, 97.08%). Other publication languages included Portuguese (43 papers, 0.83%), French (24 papers, 0.47%), Chinese (19 papers, 0.37%), Spanish (18 papers, 0.35%), German (12 papers, 0.23%), and Polish (11 papers, 0.21%).

2. Publication output

Figure 1 illustrates the temporal distribution of publications on soil pollution research between 1990 and 2024. The highest annual output was recorded in 2022, with 580 papers.

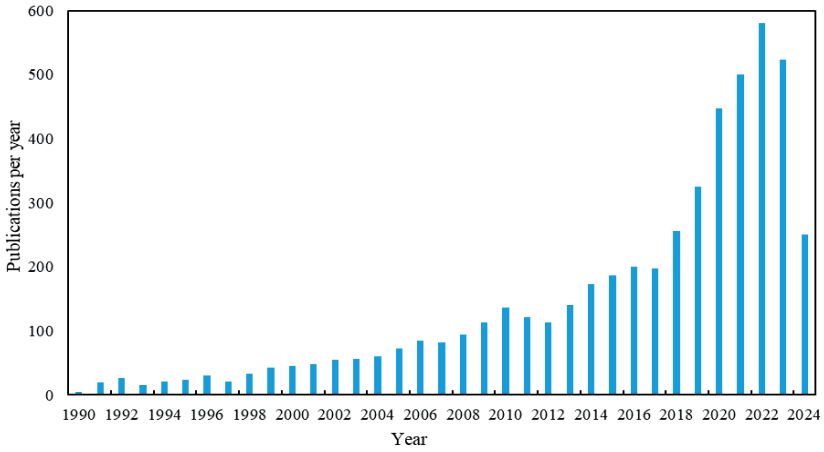

Figure 1. Trends in the quantity of published papers on soil pollution topic research from 1990 to 2024

The number of publications increased steadily over the decades, with 239 papers published between 1990 and 1999, 711 papers from 2000 to 2009, 1,851 papers during 2010 to 2019, and 2,302 papers between 2020 and 2024. An additional 62 papers were published between 1903 and 1989, although this early period is not represented in Figure 1 due to the low volume. Cumulatively, the 5,166 papers have an h-index of 144 and a total citation count of 140,047, resulting in an average of 27.11 citations per paper**.** The earliest identified publication on the topic of soil pollution is titled *"Soil Pollution and Disease in Camps"*, authored by Caldwell in 1903 and published in the *British Medical Journal.*

3. Web of Science categories and research areas

Between 1903 and 2024, publications related to soil pollution were distributed across 152 Web of Science (WoS) subject categories and 97 research areas.

Table 1 presents the top 20 categories and areas based on the number of published papers.

Table 1. Top 20 WoS categories and research areas on soil pollution topic research from 1903 to 2024

Rank	WoS categories				Research areas		
	Categories	No. papers	% total papers		Areas	No. papers	% total papers
1	Environmental Sciences	3,033	58.711			3,166	61.285
2	Soil Science	521	10.085		Agriculture	781	15.118
3	Water Resources	505	9.775		Engineering	648	12.544
4	Engineering Environmental	475	9.195		Water Resources	505	9.775
5	Public Environmental Occupational Health	283	5.478		Chemistry	375	7.259
6	Toxicology	247	4.781		Science Technology Other Topics	317	6.136
7	Geosciences Multidisciplinary	232	4.491		Public Environmental Occupational Health	283	5.478
8	Plant Sciences	224	4.336		Toxicology	247	4.781
9	Agronomy	189	3.659		Geology	243	4.704
10	Green Sustainable Science Technology	177	3.426		Plant Sciences	224	4.336
11	Meteorology Atmospheric Sciences	171	3.31		Meteorology Atmospheric Sciences	171	3.31
12	Chemistry Analytical	158	3.058		Geochemistry Geophysics	126	2.439
13	Ecology	157	3.039		Biotechnology Applied Microbiology	103	1.994
14	Environmental Studies	147	2.846		Materials Science	91	1.762
15	Chemistry Multidisciplinary	139	2.691		Biochemistry Molecular Biology	75	1.452
16	Geochemistry Geophysics	126	2.439		Biodiversity Conservation	63	1.22
17	Multidisciplinary Sciences	121	2.342		Energy Fuels	62	1.2
18	Engineering Chemical	116	2.245		Physics	61	1.181
19	Agriculture Multidisciplinary	104	2.013		Microbiology	54	1.045
20	Biotechnology Applied Microbiology	103	1.994		Food Science Technology	44	0.852

The top five categories included Environmental Sciences (3,033 papers, 58.711%), Soil Science (521 papers, 10.085%), Water Resources (505 papers, 9.775%), Engineering Environmental (475 papers, 9.195%), Public Environmental Occupational Health (283 papers, 5.478%). The top five research areas include Environmental Sciences Ecology (3,166 papers, 61.285%), Agriculture (781 papers, 15.118%), Engineering (648 papers, 12.544%), Water Resources (505 papers, 9.775%), Chemistry (375 papers, 7.259%).

4. Core journals

All 5,166 publications analyzed in this study were published across 961 scientific journals and five book series**.** Table 2 presents the top 20 core journals, each of which has published more than 47 papers on the topic of soil pollution. The table includes data on the number of articles per journal, 2022 impact factor (IF), five-year impact factor, quartile ranking in the highest WoS category (if the journal belongs to multiple), total citations, and average citations per article. The top five journals are *Science of the Total Environment* (298 papers, 5.768%), *Environmental Science and Pollution Research* (218 papers, 4.22%), *Environmental Pollution* (162 papers, 3.136%), *Chemosphere* (142 papers, 2.749%), *Environmental Monitoring and Assessment* (138 papers, 2.671%). Among the top 20

journals, nine were classified in Quartile 1 (Q1), indicating the highest level of scientific impact and visibility. Three journals were ranked in Q2, another three in Q3, two in Q4, while three journals did not have an available impact factor in 2023. When assessed by average citations per article, *Geoderma* ranked highest with 63.6 citations per paper, followed by *Science of the Total Environment* (62.7), *Chemosphere* (59.3), *Environmental Pollution* (56.0), and *Journal of Hazardous Materials* (51.7). Citation network analysis further revealed that 168 journals met the minimum threshold of five published articles in this domain, with 161 of them exhibiting citation interconnections. The resulting network visualization, based on Web of Science data, identified 15 distinct clusters, each represented by a unique color in Figure 2, reflecting the thematic and collaborative structure within the field of soil pollution research.

Table 2. Top 20 core Journals on soil pollution topic research indexed in the WoS

Rank	Journal	TP	Ratio	IF 2023	IF 5year	QC	Citations	Avg. citations
1	*Science of the Total Environment*	298	5.768	8.2	8.6	Q1	18688	62.7
2	*Environmental Science and Pollution Research*	218	4.22	-	-	-	5138	23.6
3	*Environmental Pollution*	162	3.136	7.6	8.3	Q1	9079	56.0
4	*Chemosphere*	142	2.749	8.1	7.7	Q1	8425	59.3
5	*Environmental Monitoring and Assessment*	138	2.671	2.9	3.1	Q3	2855	20.7
6	*Water Air and Soil Pollution*	135	2.613	3.8	3.6	Q2	3256	24.1
7	*Environmental Geochemistry and Health*	105	2.033	3.2	4	Q2	2134	20.3
8	*Journal of Hazardous Materials*	96	1.858	12.2	11.9	Q1	4967	51.7
9	*Sustainability*	91	1.762	3.3	3.6	Q2	953	10.5
10	*Ecotoxicology and Environmental Safety*	79	1.529	6.2	6.3	Q1	2351	29.8
11	*Journal of Soils and Sediments*	79	1.529	2.8	3.3	Q3	1784	22.6
12	*Fresenius Environmental Bulletin*	75	1.452	-	-	-	250	3.3
13	*Environmental Earth Sciences*	71	1.374	2.8	3	Q3	1405	19.8
14	*Eurasian Soil Science*	71	1.374	1.4	1.4	Q4	434	6.1
15	*Journal of Geochemical Exploration*	67	1.297	3.4	3.4	Q1	2622	39.1
16	*Journal of Environmental Management*	62	1.2	8	7.9	Q1	2728	44.0
17	*International Journal of Env. Research and Public Health*	60	1.161	-	-	-	873	14.6
18	*Environmental Research*	53	1.026	7.7	7.5	Q1	1711	32.3
19	*Polish Journal of Environmental Studies*	50	0.968	1.4	1.5	Q4	1369	27.4
20	*Geoderma*	47	0.91	5.6	6.7	Q1	2987	63.6

Note: TP: Total publications; Ratio: Ratio of 5,166 (%); IF 2023: journal impact factor in 2023; IF5 year: journal impact factor of 5 years; QC: Quartile in category.

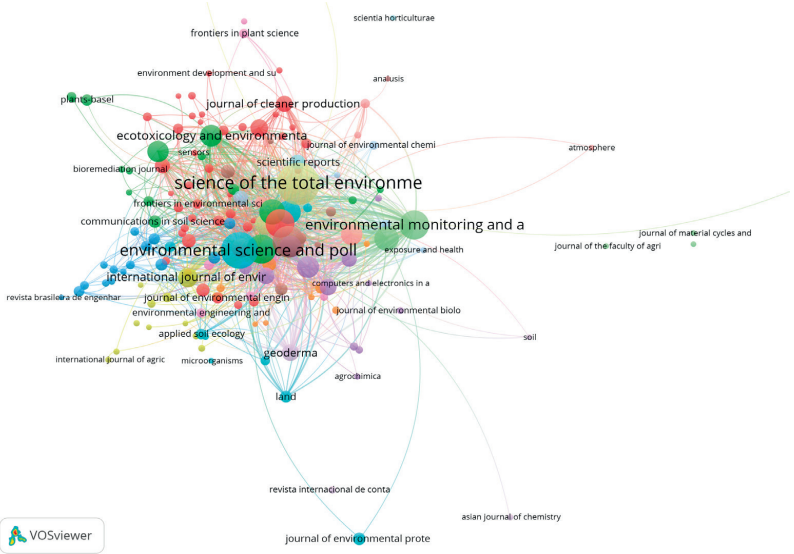

Figure 2. Network visualization maps of citation journals with minimum of 5 publications in the field of soil pollution topic research based on WoS with 161 circles and fifteen clusters

5. Countries/regions co-authorship analysis

A total of 129 countries or regions contributed to the 5,166 publications analyzed in this study.

Table 3 presents the top 20 contributors, each having published at least 90 papers on soil pollution, as indexed in the Web of Science Core Collection. Among these, the leading contributors were the People's Republic of China, Spain, the United States, Poland, and India, each of which produced more than 275 publications.

Out of the 129 participating countries or regions, 91 met the minimum threshold of five publications required for inclusion in the co-authorship network analysis. Of these, 90 demonstrated active collaborative relationships and were interconnected through co-authorship links.

The resulting international collaboration network was visualized and categorized into nine distinct clusters, as shown in Figure 3, illustrating the structural patterns of global cooperation and regional research alliances within the domain of soil pollution.

Table 3. Top 20 countries published papers in the field of soil pollution topic research based on WoS

Rank	Countries/Regions	Records	% of 5,166
1	Peoples R China	1,544	29.888
2	Spain	372	7.201
3	USA	325	6.291
4	Poland	292	5.652
5	India	275	5.323
6	Italy	246	4.762
7	Russia	230	4.452
8	Iran	222	4.297
9	France	214	4.142
10	Brazil	196	3.794
11	Germany	174	3.368
12	Turkey	164	3.175
13	England	130	2.516
14	Pakistan	125	2.42
15	Romania	112	2.168
16	Netherlands	105	2.033
17	Saudi Arabia	97	1.878
18	Czech Republic	94	1.82
19	South Korea	94	1.82
20	Egypt	90	1.742

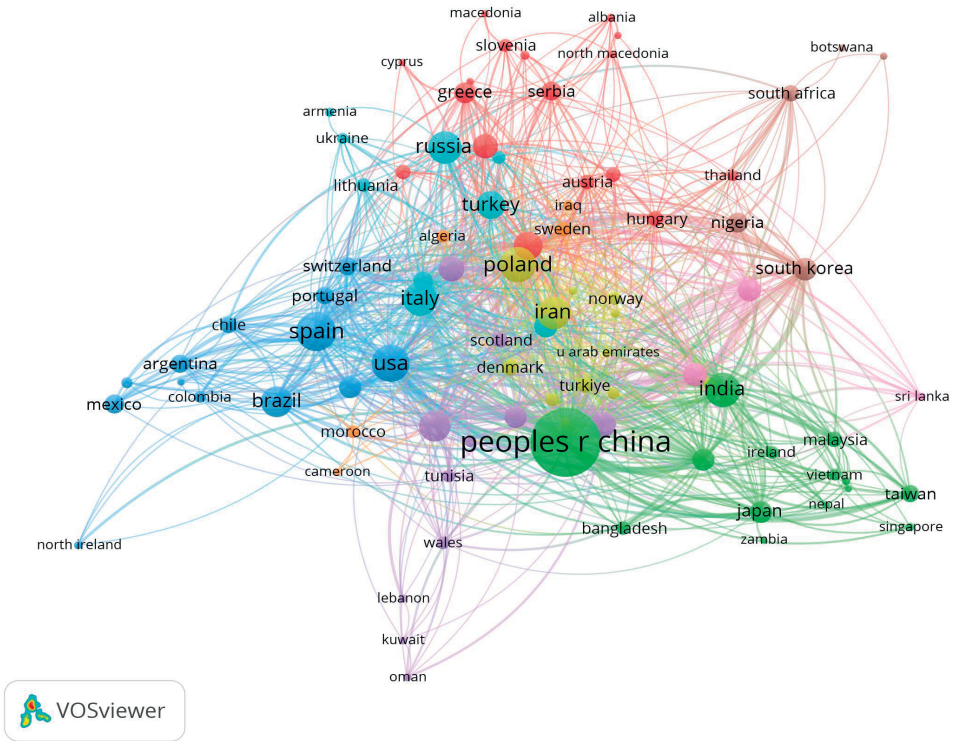

Figure 3. The country co-authorship network map of soil pollution topic research based on WoS with 90 nodes and nine clusters

The co-authorship network, based on publication volume, revealed a structured distribution across nine clusters.

The first cluster (red) comprised seventeen countries or regions, including Germany, Romania, and others. The second cluster (green) included fourteen countries or regions, most notably the People's Republic of China and India. The third cluster (blue) consisted of thirteen countries or regions, such as Spain, the United States, and Brazil.

The fourth cluster (yellow) encompassed twelve countries or regions, including Poland and Iran. The fifth cluster (violet) contained eleven countries or regions, with France, Pakistan, and England among the notable contributors. The sixth cluster (light blue) was composed of ten countries or regions, including Italy, Russia, and Turkey. The seventh cluster (orange) included five countries or regions, such as Sweden and Morocco, while the eighth cluster (pink) also comprised five countries or regions, including South Korea and Nigeria. Lastly, the ninth cluster (brown) consisted of three countries or regions: Saudi Arabia, Egypt, and Sri Lanka.

6. Organizations (Affiliations) co-authorship analysis

According to publication data from the Web of Science, a total of 4,636 organizations contributed to the 5,166 papers analyzed in this study.

Table 4 lists the top 15 organizations, each of which produced more than 49 publications, along with their respective share of the total output and country of origin.

The five most prolific institutions were the Chinese Academy of Sciences (339 publications, 6.56%), the University of Chinese Academy of Sciences (116, 2.25%), the Consejo Superior de Investigaciones Científicas (CSIC) in Spain (100, 1.94%), the Centre National de la Recherche Scientifique (CNRS) in France (98, 1.90%), and the Russian Academy of Sciences (97, 1.88%). Among the top 15 organizations, nine were based in China, two in France, two in Russia, and one in Spain, indicating a strong research presence from institutions in East Asia and Europe in the field of soil pollution.

Table 4. Top 15 organizations publishing papers in the field of soil pollution topic research based on WoS

Rank	Organizations	Records	% of 5,166	Country
1	Chinese Academy of Sciences	339	6.562	China
2	University of Chinese Academy of Sciences CAS	116	2.245	China
3	Consejo Superior De Investigaciones Cientificas CSIC	100	1.936	Spain
4	Centre National De La Recherche Scientifique CNRS	98	1.897	France
5	Russian Academy of Sciences	97	1.878	Russia
6	Egyptian Knowledge Bank EKB	89	1.723	Egypt
7	Zhejiang University	73	1.413	China
8	INRAE	69	1.336	France
9	Nanjing Institute of Soil Science CAS	66	1.278	China
10	Lomonosov Moscow State University	60	1.161	Russia
11	Institute of Geographic Sciences Natural Resources Research CAS	58	1.123	China
12	China University of Geosciences	51	0.987	China
13	Research Center for Eco Environmental Sciences RCEES	51	0.987	China
14	Chinese Academy of Agricultural Sciences	50	0.968	China
15	Northwest A F University China	49	0.949	China

7. All Keywords co-occurrence analysis

Using the full counting method for co-occurrence analysis, a total of 11,242 author keywords were identified. Among these, 584 keywords met the minimum threshold of five occurrences and were grouped into eighteen clusters in the resulting network map visualization. The twenty most frequently co-occurring author keywords - each appearing more than 70 times - were: *soil pollution*, *heavy metals*, *soil*, *heavy metal*, *phytoremediation*, *cadmium*, *soil contamination*, *pollution*, *risk assessment*, *lead*, *trace elements*, *bioremediation*, *spatial distribution*, *ecological risk*, *arsenic*, *soil remediation*, *remediation*, *potentially toxic elements*, *biochar*, and *contamination*. Each author's keywords occurred more than 70 times.

For Keywords Plus, 7,730 terms were identified, of which 931 met the threshold of five occurrences. These were grouped into twelve clusters in the network visualization.

The top twenty Keywords Plus, each occurring more than 202 times, included: *heavy-metals*, *contamination*, *pollution*, *cadmium*, *accumulation*, *lead*, *sediments*, *agricultural soils*, *trace-elements*, *toxicity*, *water*, *spatial-distribution*, *plants*, *zinc*, *copper*, *polycyclic aromatic hydrocarbons*, *growth*, *urban soils*, and *area*. Each keyword plus occurred more than 202 times.

In total, 17,223 unique keywords were identified. Based on increasing thresholds of five, six, seven, and eight occurrences, 1,470, 1,205, 1,023, and 880 keywords met the respective criteria. These were ultimately grouped into seven main clusters, each representing a distinct thematic perspective within the field of soil pollution research, as illustrated in Figure 4.

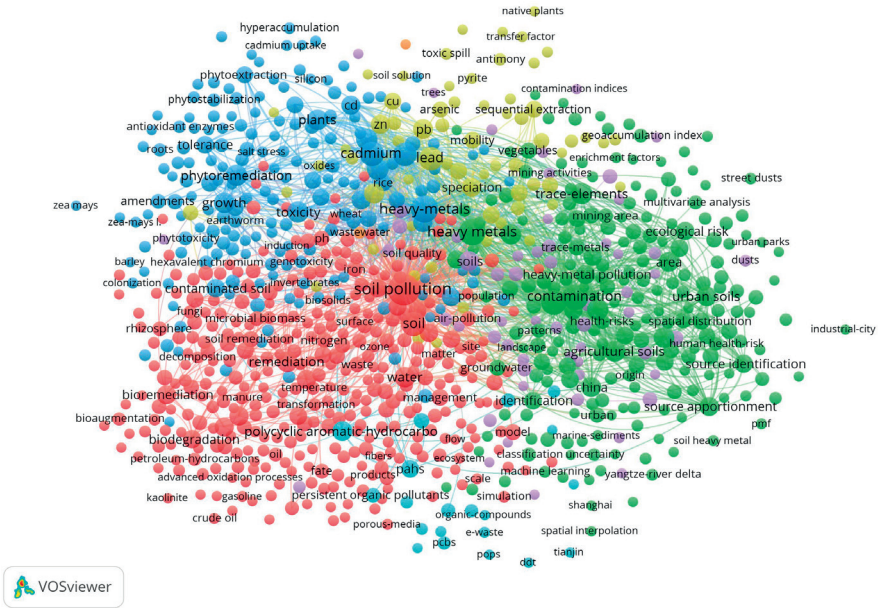

Figure 4. VOSviewer co-occurrence network visualization mapping of most frequently all keywords on soil pollution topic research with seven main clusters. Co-occurrence network of all keywords including author keywords and keywords plus

The top twenty most frequently co-occurring keywords across all sources included: *soil pollution*, *heavy-metals*, *heavy metals*, *contamination*, *pollution*, *soil*, *cadmium*, *lead*, *accumulation*, *sediments*, *agricultural soils*, *zinc*, *trace-elements*, *phytoremediation*, *toxicity*, *copper*, *water*, *remediation*, *plants*, and *spatial-distribution*. Each of these keywords appeared more than 257 times.

The same dataset visualized in Figure 4 was further analyzed by time period and presented as an overlay map in Figure 5. In this temporal visualization, blue-colored nodes represent earlier research topics, while yellow and green nodes indicate more recent areas of focus, highlighting current research fronts.

The seven thematic clusters identified in Figure 4 encompass a broad range of subfields within soil pollution research. These include: (1) soil pollution remediation, (2) soil heavy metal contamination, (3) heavy metal accumulation and phytoremediation, (4) bioavailability and extraction of heavy metals, (5) soil dust and particulate matter impacts on vegetation, (6) polycyclic aromatic hydrocarbons (PAHs), and (7) wastewater and metal toxicity.

The first cluster (red in Figure 4) consists of 347 keywords that met the threshold of eight occurrences and primarily focuses on *soil pollution remediation*. The 20 most frequently used keywords in this cluster include: *soil*

pollution, *soil*, *water*, *remediation*, *adsorption*, *bioremediation*, *removal*, *degradation*, *impact*, *organic matter*, *biodegradation*, *environment*, *quality*, *sorption*, *wastewater*, *biochar*, *diversity*, *sewage sludge*, *management*, and *extraction*, each appearing more than 87 times.

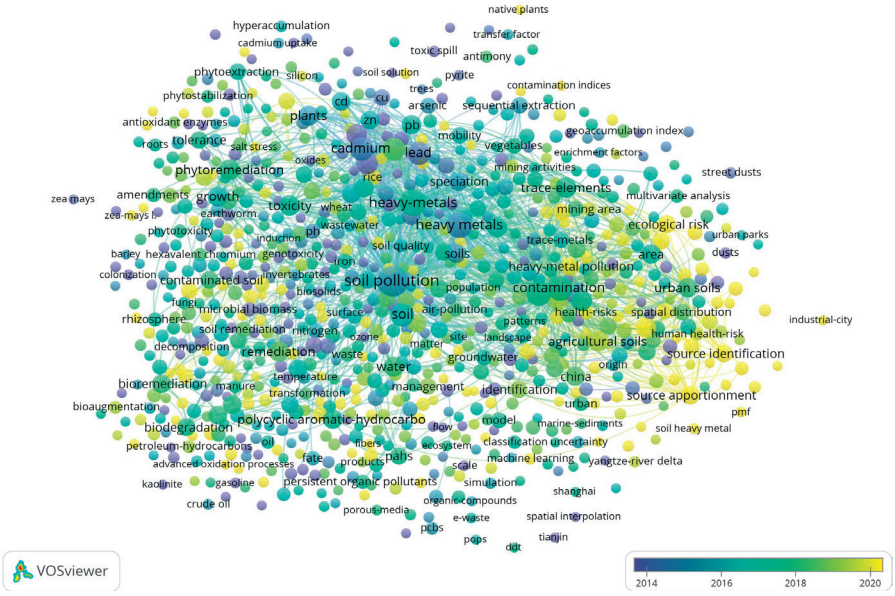

Figure 5. VOSviewer co-occurrence overlay visualization mapping of most frequently all keywords on soil pollution topic research. The years in which specific keywords frequently occur are shown by different colours

The second cluster (green) includes 206 keywords and represents research on *heavy metal contamination of soil*. This was identified as a front-line research theme. The top 22 keywords in this cluster, each with more than 123 occurrences, are: *heavy metals*, *contamination*, *pollution*, *sediments*, *agricultural soils*, *trace elements*, *spatial distribution*, *heavy metal*, *urban soils*, *China*, *area*, *source apportionment*, *heavy-metal pollution*, *ecological risk*, *elements*, *risk assessment*, *soil contamination*, *source identification*, *health risk*, *city*, *risk assessment*, and *identification*.

The third cluster (blue) comprises 183 keywords and centers on *heavy metal accumulation and phytoremediation*. The 21 most frequent terms in this group include: *heavy metals*, *cadmium*, *accumulation*, *zinc*, *phytoremediation*, *toxicity*, *copper*, *plants*, *growth*, *contaminated soils*, *Cd*, *metals, contaminated soil, contaminated soil*, *contaminated soil*, *exposure*, *tolerance*, *bioaccumulation*, *oxidative stress*, *phytoextraction*, *availability*, *plant*, and *chromium*, each occurring more than 84 times.

The fourth cluster (yellow) consists of 65 keywords and addresses *the bioavailability and extraction of various heavy metals*. The top 20 terms - each mentioned more than 35 times - include: *lead*, *Pb*, *bioavailability*, *speciation*, *Zn*, *trace elements*, *mercury*, *Cu*, *mobility*, *sequential extraction*, *fractionation*, *arsenic*, *mine*, *immobilization*, *sequential extraction procedure*, *mine tailings*, *tailings*, *toxic metals*, *manganese*, and *Spain*.

The fifth cluster (violet) comprises 57 keywords and focuses on *the effects of soil dust and particulate matter on vegetation*. The 20 most common keywords include: *soils*, *dust*, *particulate matter*, *vegetation*, *fly ash*, *heavy metal*, *magnetic susceptibility*, *vicinity*, *deposition*, *susceptibility*, *samples*, *particles*, *metal pollution*, *parameters*, *forest soils*, *atmospheric deposition*, *PAH*, *topsoil*, *Turkey*, and *India*, each with more than 20 occurrences.

The sixth cluster (light blue) includes 20 keywords and is centered on *polycyclic aromatic hydrocarbons (PAHs)*. Frequent keywords in this group, each appearing more than eight times, are: *polycyclic aromatic hydrocarbons*, *PAHs*, *persistent organic pollutants*, *polychlorinated biphenyls*, *air*, *organochlorine pesticides*, *PCBs*, *polybrominated diphenyl ethers*, *sites*, *dibenzo-p-dioxins*, *e-waste*, *DDT*, *fluxes*, *organic compounds*, *dry deposition*, *POPs*, *Tianjin*, and several variants of polychlorinated substances.

The seventh cluster (orange) is the smallest, consisting of only two keywords: *wastewater* and *metal toxicity*, each of which appeared more than eight times.

8. Burst of keywords

A keyword burst analysis was conducted using CiteSpace (Basic version 6.2.R6) to identify emerging trends and research hotspots in the field of soil pollution. The analysis focused on the top 25 keywords exhibiting the strongest citation bursts between 1994 and 2024, as shown in Figure 6.

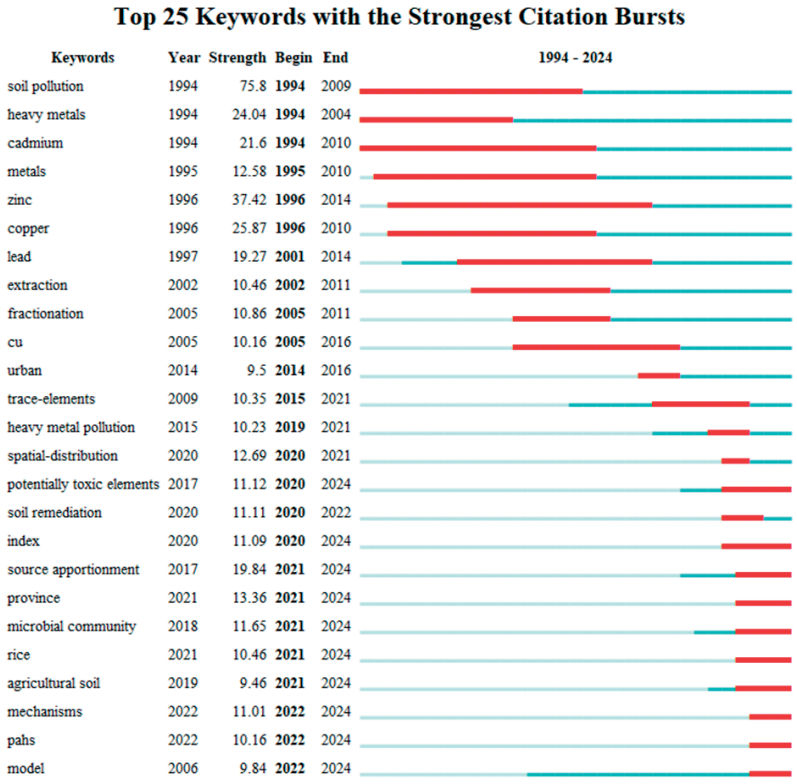

Figure 6. Information about top 25 keywords of soil pollution topic research with the strongest citation bursts from 1994 to 2024 by CiteSpace (6.2.R6). Begin, year when the burst begins; End, year when the burst ends. Red grids indicate the years when a particular term started to be frequently used. A longer the red bar, the keywords have been cited for a longer duration

These keywords - indicative of sudden increases in scholarly attention - include: *soil pollution*, *heavy metals*, *cadmium*, *metals*, *zinc*, *copper*, *lead*, *extraction*, *fractionation*, *Cu*, *urban*, *trace elements*, *heavy metal pollution*, *spatial distribution*, *potentially toxic elements*, *soil remediation*, *index*, *source apportionment*, *province*, *microbial community*, *rice*, *agricultural soil*, *mechanisms*, *PAHs*, and *model*. These terms reflect the evolving focus and interdisciplinary nature of soil pollution research over the past three decades.

9. Top papers based on Essential Science Indicators (ESI)

The analysis of top-cited literature was conducted using the Essential Science Indicators (ESI) database, which was last updated on July 11, 2024, and covers a 10-year and 4-month period from January 1, 2014, to April 30, 2024**.** According to ESI data, a total of 72 top papers were identified, including 72 highly cited papers and one hot paper**.**

These publications span a range of years, with distribution as follows: 2014 (5 papers), 2015 (4), 2016 (2), 2017 (2), 2018 (8), 2019 (6), 2020 (10), 2021 (11), 2022 (10), 2023 (12), and 2024 (2). The journals that published multiple top papers include: *Science of the Total Environment* (14 papers), *Environmental Research* (7), *Journal of Hazardous Materials* (6), *Environmental Pollution* (3), *Journal of Environmental Management* (3), *Chemosphere* (2), *Environment International* (2), *Environmental Science & Technology* (2), *Journal of Water Process Engineering* (2), and *Water, Air, and Soil Pollution* (2).

These findings underscore the prominence of multidisciplinary environmental science journals in disseminating high-impact research on soil pollution.

10. The most frequently cited articles

The annual citations of the eight papers showed an increasing trend after a year of publication (Figure 7). The eight papers were written by Li et al (2014), Duruibe et al (2007), Facchinelli et al (2001), Chen et al (2015), Bläsing and Amelung (2018), Michalak (2006), Goovaerts (1999), Manta et al (2002). From the publication year to July 20, 2024, the total citations for each paper of the most citation eight papers were 2082, 1296, 1117, 1030, 880, 867, 837 and 810 times, and the average citation per year each paper were 189.3, 72.0, 46.5, 103.0, 125.7, 45.6, 32.2 and 35.2 times.

Among the eight articles, the highest average citation paper per year were 189.3 (Li et al, 2014), also includes two papers both Chen et al (2015) and Bläsing and Amelung (2018), which were the top papers (highly cited paper) based on ESI.

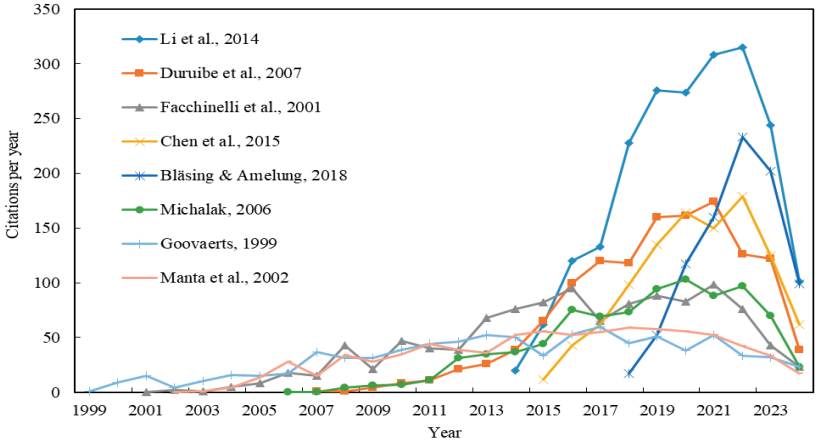

Figure 7. Comparison of the citations per year of the eight papers related to soil pollution topic research from their initial publications to July 20, 2024

11. Sustainable development goals

Table 5 presents the distribution of soil pollution research papers in relation to all Sustainable Development Goals (SDGs).

The analyzed papers addressed thirteen of the Sustainable Development Goals (SDGs), with the highest concentration of research focused on five key goals: SDG 11 – Sustainable Cities and Communities, SDG 2 – Zero Hunger, SDG 13 – Climate Action, SDG 3 – Good Health and Well-Being, and SDG 15 – Life on Land.

Table 5. All Sustainable Development Goals for soil pollution topic research papers

Rank	Sustainable Development Goals	Record Count	% of 5,166
1	11 Sustainable Cities and Communities	2144	41.502
2	02 Zero Hunger	638	12.35
3	13 Climate Action	556	10.763
4	03 Good Health and Well Being	509	9.853
5	15 Life on Land	477	9.233
6	06 Clean Water and Sanitation	443	8.575
7	12 Responsible Consumption and Production	120	2.323
8	14 Life Below Water	120	2.323
9	07 Affordable and Clean Energy	20	0.387
10	01 No Poverty	8	0.155
11	09 Industry Innovation and Infrastructure	8	0.155
12	04 Quality Education	6	0.116
13	16 Peace and Justice Strong Institutions	4	0.077

CONCLUSIONS

This study conducted a comprehensive bibliometric analysis of 5,166 publications related to soil pollution research. The leading journals contributing to this field include *Science of the Total Environment*, *Environmental Science and Pollution Research*, *Environmental Pollution*, *Chemosphere*, and *Environmental Monitoring and Assessment*. In terms of national contributions, the top five publishing countries were the People's Republic of China, Spain, the United States, Poland, and India.

Through co-occurrence network visualization using VOSviewer, author keywords were categorized into seven thematic clusters, highlighting the multidimensional nature of soil pollution research. Additionally, most papers aligned with three key Sustainable Development Goals (SDGs): SDG 11 – Sustainable Cities and Communities, SDG 2 – Zero Hunger, and SDG 13 – Climate Action.

The findings of this analysis not only reflect the current landscape and emerging trends in soil pollution research but also offer valuable insights to guide future investigations and interdisciplinary collaborations in this critical environmental domain.

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