Mapping of Heavy Metal Pollution in River System: A Scientometric Approach

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ABSTRACT
Bioaccumulation and biotransformation of heavy metals cause serious pollution in aquatic ecosystems. This has attracted widespread attention to its negative effect on ecological and human health. In recent years, several studies have been done in this area. Among all the heavy metals, Cadmium (Cd) and lead (Pb) have been widely reported for their toxic effect. However, detailed research activity on these two pollutants in aquatic ecosystems has not been mapped. It is important to capture the key topics and domains in which research is happening. The present study attempts to address this gap. A detailed Scientometrics study was undertaken to capture the heavy metal pollution in river systems. The 33,414 research papers were identified from a topic search covering the period 2010 to 2021 from the 'web-of-science' database. The social network analysis approach was used for understanding the structure and dynamics of the research. The study identifies the following as major nodes in the network constructed from author keywords assigned to the research papers namely heavy metal (primarily lead, cadmium), bioremediation, carbon nanotube, and sequential extraction. The thematic areas were identified as ecological risk, adsorption, atmospheric deposition, and potential ecological risk as major domains of research namely. The study has implications for research assessment and alerting the community and policymakers to the concerns about the adverse effect of these metals on aquatic ecosystems.

Keywords: Heavy Metal, Lead, Cadmium, Sustainable Development, SDG 6, Scientometrics analysis.

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INTRODUCTION

Water is a key element for all the types of life existing on our earth. River water is the main source of irrigation for the agriculture system. Due to fast-track groundwater depletion and poor irrigation systems, agriculture accounts for 90% of water use. About 195 million hectares of land are used for cultivation. Of this, approximately 63% is rain-fed while the remaining agricultural land depends on irrigation. Additionally, several wildlife sanctuaries are located on the banks of rivers and their backwaters. Hence rivers are critical to their survival. Further, they also provide a livelihood to millions of people.[1]

Among the key influencers that stress water resources is the population size and growth as there is an increasing need for water for industrial and agricultural growth along with fulfilling the basic need of drinking water. This development deteriorates the quality and quantity of water resources. More than 30% of the world's population does not have access to safe drinking water.[2,3]

In a developing nation, the importance of surface water sources is very high, considering their requirement for various domestic, commercial, and irrigation activities. Consequently, examining the pollution status in surface water sources, especially rivers is very significant.[4] Various water quality indices had been developed by quantifying the levels of pollution and consistent monitoring of the various river water quality parameters. Among all the contamination indices, the Heavy Metal Pollution Index (HPI) was found to become the most efficient method for ranking the quality of water.[5] Past few decades, heavy metal pollution has been one of the major global issues due to its abundance, bioaccumulation, and non-degradable nature.[6] Heavy metal toxicity possesses harmful effects on ecological, evolutionary, nutritional, and environmental areas. The presence of heavy metals in river water above their permissible level may cause a significant threat to human health and environmental systems. Riverine systems can transport heavy metals to hundreds of kilometres along the hydrological gradient in a relatively short period. This may be responsible for creating toxic effects at points distant from the source of contamination.[7]

India epitomises to a large extent the challenges of water availability and quality. Thus, some insights from India are useful to put the key issues in context. As per BIS (Bureau of Indian Standards),

each metal has its permissible limit in the environment. Metals are important nutritional constituents that play an important role in the functioning of living organisms. Beyond a limit, they cause health and environmental problems. Among the non-nutrient and highly toxic heavy metals, Cd (cadmium) and Pb (Lead) are the two most highly prevalent heavy metals in the Indian River system.[8]

Cadmium is an element that occurs naturally and uniformly distributed in the Earth's crust. It is generally estimated to be present at an average concentration of 3 µg/L as per WHO (World Health Organization) and 5 µg/L as per USEPA (United States Environmental Protection Agency). The major sources of water contamination by cadmium are industrial discharge and leaching from landfill areas. Drinking water is generally contaminated with a galvanized iron pipe and plated plumbing fitting of the water distribution pipes. It ranks next to mercury in its toxicity. The gastrointestinal tract is the major route of Cd uptake in both humans and animals. However, only a small amount of cadmium intake is absorbed by the body and is stored mainly in bones, liver, and, in case of chronic exposure, kidneys. The widely reported Cd poisoning itai-itai boy occurred in Japan after World War II. There was severe pain in the body and joints and the people cried ITAI –ITAI (it hurts-it hurts). Lead (Pb) is the most common heavy metal. It is generally estimated to be present at an average concentration of 10 µg/L as per WHO and 15 µg/L as per USEPA. Among the several stable isotopes that exist in nature, $_{208}$Pb is the most abundant. It is used mainly in the production of lead-acid batteries, solder, and alloys. Though it is a non-nutritional element it is found in all human tissues and organs. It is known as one of the systemic poisons because, once absorbed into the circulation it will distribute throughout the body, where it affects various organs and tissues. It inhibits haematopoiesis because it interferes with heme synthesis, and may cause anaemia. According to the CDC (Centres for Disease Control and Prevention, US Federal Agency), lead poisoning is the most common and serious environmental disease affecting young children.

Thus, considering the role of river water in human sustenance, it is important to monitor and regulate the water quality efficiently. An increase in the number of toxic pollutants from multiple sources makes the characterization of pollutants practically in-executable.[9,10] An integrated multidisciplinary approach has been devised for accurate monitoring of pollution status across the globe. This study attempts to capture global influential research and insights on the scenario of the river water system concerning heavy metal pollution. It does an exhaustive analytical examination of research papers in this area to discover where and what type of research is happening in this domain globally.

LITERATURE REVIEW

In a couple of years, the acceleration in industrialization has led to an increase in heavy metal emissions. Activities like mining, smelting and metal treatment, traffic, and dumpsite areas cause heavy metal pollution which is a serious threat to human health.[11] Continuously, one by one various incidents occur in succession that increase the risk of heavy metals to human health, and still, their results are seen in young generations. *For example,* Minamata disease in Japan is caused due to mercury pollution, and itai-itai disease is caused by cadmium pollution.[12] In Bangladesh, arsenic and lead contamination cause various health problems in children.[13] This is also prevalent in the eastern part of India. Various studies show that most heavy metals and metalloids are carcinogens and affect the aetiology of several diseases, such as cardiovascular, kidney, nervous system, blood, and bone diseases.[14] The everlasting metal toxicity threat for the aquatic environment has been enhanced recently and Cadmium (Cd) and Lead (Pb) are considered major environmental problems due to their high carcinogenic and anticarcinogenic toxicities.[15] They have a long-term existence and are highly toxic to humans, plants, and animals.[16] Once absorbed, they cause infections in the liver and kidneys, and now emerging evidence suggests their genetic toxicity.[17] In aquatic ecosystems, Cd and Pb exposure can increase the formation of Reactive Oxygen Species (ROS) in cells, which leads to oxidative damage to biological systems.[18]

Heavy metals are non-biodegradable, they only convert from active form to inactive form by a wide range of processes and pathways.[19] On the other hand, due to the high toxicity, bioaccumulation, and bio-enrichment, heavy metal pollution is still a major problem of global concern and has received increasing attention. Scientists conduct extensive research on heavy metal emissions, pollution, health risk assessments, and pollution control and management which provide valuable information.[20] Maurya *et al*., 2019 studied the Bioaccumulation and potential sources of heavy metal contamination in fish species in the river Ganga basin and its possible human health risks.[21] They observed the presence of five heavy metals Zn, Pb, Cu, Cd, and Cr in most consumable fish species i.e., *Cirrhinus mrigala, Cirrhinus reba, Catla catla, Lebio rohita, Crossocheilus latius, Clupisoma garua,* and *Mystus tengara*, collected from local markets of Varanasi, Allahabad, Mirzapur, and Kanpur of Uttar Pradesh, India. Similarly, Rajesh Kumar and Li, 2018 studied the Bioaccumulation of heavy metals in fish species from Meiliang Bay, Taihu Lake, a large, shallow, and eutrophic lake in China.[22] They observed the accumulation of heavy metals (Cr, Cu, Cd, Pb) content in freshwater edible fishes *Cyprinus carpio Linnaeus* and *Pelteobagrus fulvidraco*. Therefore, it is essential to have a global overview of sources, human health risk factors, and control strategies for heavy metals. This will help to identify research trends, track research hotspots, and determine research direction in future years.

Bibliometric analysis is an effective and widely accepted method to identify research trends and hot issues based on research publications.[23] Scientists have already conducted various scientometric analysis reports on heavy metal pollution in the soil ecosystem as well as the groundwater system. Ouyang *et al.*, 2018, comprise a report which explores various factors related to heavy metal loss from agricultural watersheds to the aquatic ecosystem.[20] Irfan *et al.*, 2021 present the global trend of cadmium in freshwater with the help of bibliometric analysis.[24] Li *et al.*, 2019 present various research hotspots and trends in the phytoremediation of heavy metal through various qualitative and quantitative bibliometric and scientometric analysis methods.[25] Wang *et al.*, 2021, present the recent trends in source appointment of soil heavy metals by scientometric analysis.[26] They cover the research trend of 20 years from 2000 to 2020. No such study has been done that captures the overall research on heavy metal pollution in river systems and draws insights into the key domains where research is happening and draws detailed insights from that. This article attempts to address this gap by mapping the global research on heavy metal pollution in the river water system.

OBJECTIVE AND RESEARCH QUESTIONS

The key purpose of this study is to analyse the research output on heavy metal pollution using publications covering the period 2010 to 2021. This study intends to develop a comprehensive and systematic assessment of water pollution; understand the research trends and thereby recognize the areas of major research intensity and areas which need more research attention. More specifically, this study focuses on the growth pattern, both observed and expected by key institutions, countries, and most-productive researchers who are contributing significantly to the development of core domain knowledge and understanding the behaviour of the knowledge networks therein. India is taken as a specific case for investigation as it epitomises the challenges of river pollution to a large extent in developing countries.

This study attempts to capture insights into the following aspects:

- The global structure and dynamics of research in heavy metal pollution in river water

- The areas of research activity where India is prominently present

Based on the above, it draws implications for research and policy. The paper contributes to the current discussion on Sustainable Development Goal 06 on clean water and sanitation.

METHODOLOGY

Social Network Analysis (SNA) tools and techniques were used to analyse the data. SNA helps to understand the structure and dynamics of a research field, particularly useful in bringing out the relational and positional characteristics of a network. This provided a deeper insight to capture how the research is happening in this area. Papers covered by the Web of Science (WoS) database for the period 2010-2021 was the analytical set for this study.[27] The Study uses two centrality measures i.e., Degree centrality and Betweenness centrality. Degree Centrality helps to find the central node in the Network. While Betweenness centrality measures the number of times a node lies on the shortest path between other nodes. Keywords co-occurrence analysis to recognize and monitor the direction of research and development in the respective hotspot areas.[28] Keyword Cluster analysis is used to
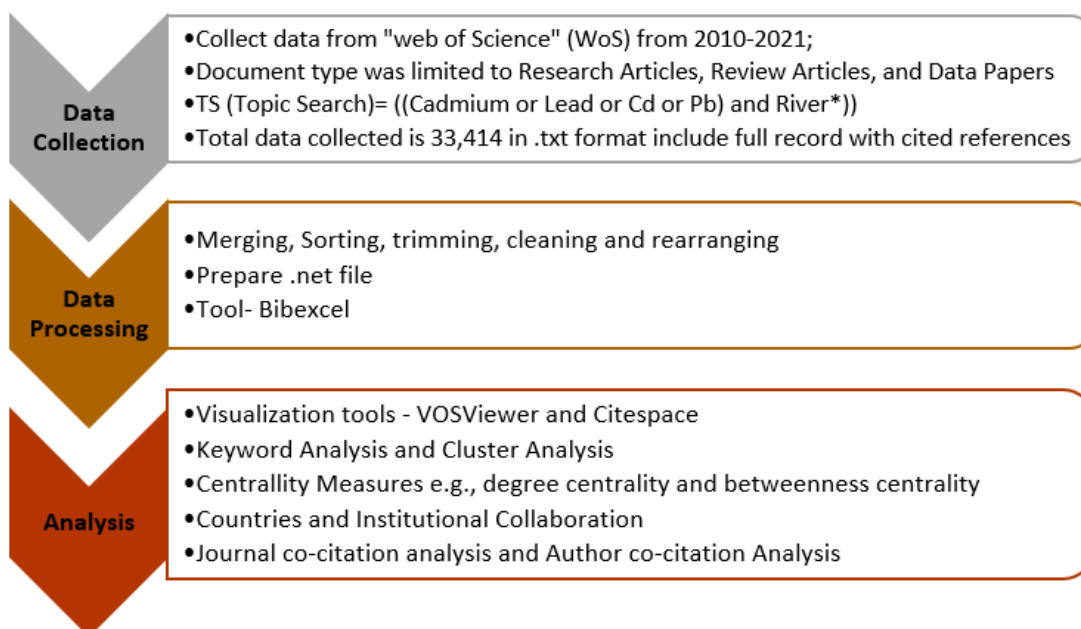

Figure 1: Conceptual framework of Methodology

group similar keywords to create several clusters having the same characteristics. Journal co-citation analysis was used to identify operational indicators for the heavy metals. Author Co-citation Analysis (ACA) is used to map knowledge domains and depict scientific intellectual structures.

Data

The papers were extracted from the WoS Topic search field using the search string ((Cadmium or Lead or Cd or Pb) and River*). The topic search field implies all papers extracted that have this string in the title or abstract. The document type was limited to research and review articles and covered full records with cited references.

The study undertook a systematic process to clean the data and remove redundancy. A set of representative keywords for example was identified through an elaborate process. Those keywords were removed which had very less connection with our search topic. These are isolates identified through the SNA analysis. Keyword having the same meaning and differs only by singular and plural were combined. Keywords have the same meaning but are denoted by using different descriptions combined i.e., Lead and Pb, metal, and element.

The data was exported from Web of Science, as plain text that included all the Bibliometric information including title, abstract, authors, keywords, references, and citation data which are needed for analysis. The first important task was preparing the data for SNA-based analysis. The network files and map coordinates were prepared in Bibexcel. Analytics and visualisation were done using VOSviewer. CiteSpace was applied to undertake a more sophisticated analysis of citation, co-citation, and geographical distribution analysis and thus helps to draw an important conclusion.[20]
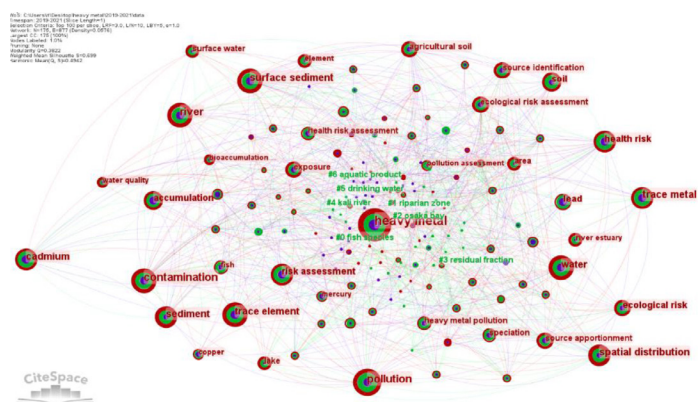

Figure 2: Keyword analysis shows the research area network of heavy metal pollution.

Table 1: Top 10 keywords with their occurrence frequency and centrality measure.

Keywords (2010-2021)	Frequency	Degree Centrality	Betweenness Centrality
Heavy metal	292	46	0.47
Contamination	140	29	0.18
River	122	23	0.15
Surface sediment	96	17	0.11
Spatial distribution	78	15	0.09
Accumulation	59	13	0.07
Trace metal	78	12	0.06
Water	74	11	0.05
Sediment	74	9	0.04
Cadmium	68	9	0.04
Health risk	64	8	0.03

RESULTS AND DISCUSSION

Publications Trend

An increase in the number of publications from 2010-2021 signifies progress in the field of heavy metal pollution. We observed 5105, 6677, 9088, and 12544 publications in the year 2010-2012, 2013-2015, 2016-2018, and 2019-2021 respectively. Overall, 37.54% of a significant increase in the number of research publications was observed in 2019-2021 as compared to 2010-2012. This signifies that an increase in heavy metal pollution attracts our attention toward this area of research. However, metals with relatively high densities, atomic weights, or atomic numbers are known as heavy metals and thus toxic if consumed even in the concentration of ppb. For the past 11 years, this area is getting increasing attention globally.

Key Research Area

Keywords are the tool that helps the index and search engine to find articles of our interest. These words capture the essence of research articles and help to define the research issue, topic field, subfield, and methodology.[29] This study brings forth the research trend in the area of heavy metal pollution in river water systems and also the pollutants and diseases which have evolved. In the keyword co-occurrence visualization map, each node represents a keyword and the size of the node denotes the frequency of its occurrence i.e., the larger the size of the node, the higher frequency of occurrence and vice versa (Figures 1 and 2). Three different colours represent the occurrence of that keyword in the

three particular years from 2010-2021 and their width represents the frequency of occurrence.

Insights from the figure 2 are further drawn from the centrality measure highlighted in Table 1.

Degree centrality is an important parameter as discussed in the methodology to identify the nodes which are playing a major role in the network. In Table 1 degree centrality of heavy metal is 46 denotes that it directly influences another area of research. Other new technologies and toxicology parameters are involved to explore this area of research. Accumulation of heavy metal in river water and surface sediment is on its edge. This is also the reason that these words are listed in the top ten keywords during the analysis. However, a decrease in the value of degree centrality i.e. health risk, cadmium, and sediment is much lower might be because these are the emerging topics in this area. Their occurrence is significantly high may be due to their involvement in other related areas like water quality, river, Agriculture soil, fish, ecological risk assessment, etc. this approach will give a holistic view of heavy metal contamination which help us to take appropriate action against this problem. (Table 1).

Cadmium and Lead used for search engines occur with frequencies 68 and 49 respectively. Figure 2 shows that Cd and Pb are the key heavy metals that were the most intense area of research globally. This highlights that these are the major areas of concern and thus are most actively researched. Among these, Cd and Pb are the highly researched heavy metals that may be due to higher toxicity and low ppb value. Keywords like health assessment, pollution index, human health risk assessment, contamination, and pollution connect to Cd and Pb. This shows the pervasive adverse impact of these two heavy metals. Due to urbanization and industrialization, the use of heavy metal increases day by day in various sectors like Agriculture, domestic, medicine, and various technological applications. This will lead to their day-by-day extensive distribution in the environment and increases the human health risk which may cause various incurable diseases. Cadmium and lead are among the priority metals that are of human health significance. According to the USEPA, these heavy metals are among the human carcinogens due to their systemic toxic action to induce multiple organ failure, even at lower concentrations.[30] Sequential extraction, source apportionment, and fractionation are the keywords that gave an idea about the methodology used for the extraction and identification of heavy metals in contaminated soil as well as in water samples. These extraction techniques help to classify Potentially Toxic Elements (PTEs) based on their association with phase or fraction in contaminated samples. This will help to improve the use of resources and reduce their adverse environmental effect.[31]

The presence of keywords like soil, sediment, drinking water, groundwater, estuary, fish, and tissue highlights these are a key problem domain which has attracted researchers' attention. As

we know, heavy metals are non-degradable thus they cannot undergo any microbial or chemical degradation process and persist in the soil for a longer period. Because of this, they enter the food chain either through contaminated soil or water bodies. They affect the natural physicochemical composition of soil as well as water.[32-35] Thus, it is not surprising that research activity is intense in these areas.

Speciation with frequency (30) signifies the bioavailability and mobility of heavy metals such as Cd, Pb, Cs, and Al in the soil column. This may increase the risk of potential uptake of heavy metals by plants, animals, and humans, which may cause genetic mutation in the species. Tack and Verloo defined the term speciation as "the identification and quantification of the different, defined species, forms or phases in which an element occurs".[36]

Keyword Cluster Analysis

Keyword cluster analysis presents a better scenario of a heavy metal pollution network. It is a way to group related keywords into smaller clusters with similar meanings. Based on the Silhouette value, 12 keyword clusters were created out of these 7 were listed (Table 2). Silhouette value proposed by Kaufman and Rousseeuw in 1990, acts as an indicator that shows the homogeneity of the network.[26] Its value varies between 0 and 1, and above 0.5 signifies the reliability and rationality of the cluster.[37]

These clusters denote the different aspects of heavy metal pollution. Cluster 1 and Cluster 3 give us information on how an increase in heavy metal concentration increases the risk to human health and how we assess this risk. Due to the increase in industrialization, human exposure increases exponentially toward several industrial, agricultural, domestic, and technological applications.[38] Which increases the risk of reactive oxygen species (ROS) production and oxidative stress. These factors play a key role in the toxicity and carcinogenicity of metals such as arsenic, cadmium, chromium, lead, and mercury.[30] Cluster 2 and Cluster 4 signify various terms related to the detection of heavy metal concentration in land and aquatic ecosystems and how we calculate its relativity with other environmental factors via statistical analysis. The multivariate statistical package provides various tools to assess the heavy metal contamination risk factor. It includes Cluster Analysis (CA), Principal Component Analysis (PCA), and pollution indices, such as the Water Quality Index (WQI), Trophic State Index (TSI), Ecological Risk Index (ERI), and Ecological Risk Assessment (ERA). These all parameters were used to determine water quality and the cause of anomalies.[39] The World Health Organization (WHO) uses various indices such as the geo-accumulation index (Igeo), Enrichment Factor (EF), and Contamination Factor (CF) to identify heavy metal anomalies and evaluate the results.[40]

Table 2: Differentiation of top 100 keywords into different clusters.

Cluster-ID	Size	Silhouette value	Cluster name	Keywords
1	38	0.738	Human health risk assessment	Heavy metals; pollution index; Bengal coast; contamination factor; pb-zn smelter	health risk; water quality; langat river basin; drinking water; Gibbs diagram; human health risk assessment; geo-accumulation index; food safety; cluster analysis; fish meat.
2	37	0.662	Sequential extraction	Heavy metals; Songhua River; health risk; multimedia environment; source apportionment	multivariate analysis; pollution indices; industrial soil; potential toxic metals; risk assessment; potentially toxic elements; positive matrix factorization; sediment contamination; hierarchical cluster analysis.
3	35	0.79	Statistical analysis	Heavy metals; spatial variability; environmental risks; geochemical fractionation; probabilistic ecological risk	sequential extraction; statistical analysis; rice contamination; tajan river(Iran); geochemical baseline; trace metals and metalloids; river sediments.
4	28	0.813	Ecological risk	Heavy metals; health risk; source apportionment; multimedia environment; Songhua River	health risk assessment; sediment quality; ecological risk; compositional data analysis; river Atbara; statistical analysis; sediment quality; sediment quality guidelines.
5	24	0.825	Adsorption	Heavy metals; risk assessment; stable isotopes; marine organisms; health risk; trophic transfer; aquatic organisms; estimated daily intake; gills; fish; bioaccumulation; bio-accessibility.
6	21	0.813	Atmospheric deposition	Heavy metals; non-carcinogenic risk; wastewater effluent; bioavailability; sequential extraction; tissue damage; health risk assessment; ecological risk; metallothionein; tissue damage; microbial dysbiosis; Langmuir isotherm.
7	21	0.897	Potential ecological risk.	Copper; nanocomposite; conformation	heavy metals; snow cover; ecological regions; dry deposition; risk assessment; adsorption; solid phase extraction; cadmium; lead; ion.

Cluster 5 and Cluster 7 include the keyword which signifies the study of how increases in heavy metal concentration accumulate in our dietary products and consume in our bodies. How do we assess this adverse effect of metal consumption based on daily intake? Clusters 6, 8, and 9 denote how increases in the heavy metal concentration accumulate in the ecosystem and increase the risk of toxicity. Bioaccumulation of heavy metals by organisms either land or aquatic may be passive. Variation in accumulation rate may be due to differences in assimilation or egestion. Cadmium (Cd), Lead (Pb), and Mercury (Hg) are non-essential heavy metals and have no known essential role in living organisms. These metals are extremely toxic even at low concentrations and cause the main threat to all forms of life on earth, exclusively human beings.[22]

Cluster 10 signifies various adverse effects caused by potentially toxic elements. These are naturally occurring elements that originate from the weathering of parent materials and various human activities, such as mineral resources development, metal processing, and smelting, industrial emissions, agricultural application of fertilizers and pesticides, sewage irrigation, and atmospheric transportation.[27] In a study on heavy metal content in the Red Sea, this was observed that heavy metals like Fe, Cr, Cu, Co, Zn, Mn, and Cd originating from terrestrial sources due to weathering of the Precambrian rocks located near the coastal zone, whereas Ni, As, Sb, Pb, and Hg were originating mainly by the developmental activities.[41] These elements have significantly accumulated in our environment in recent years, particularly in soil and sediment environments posing risks to the ecosystem and human health through long-term exposure, even at very low concentrations.[42] Cluster 11 signifies the term used in concern with remediation or assessment of heavy metal. Double-walled carbon nanotube Carbon Nanotubes (CNTs) are one of the most studied nanoparticles due to their various physio-chemical and electronic properties. At an industrial level, they show better application in heavy metal remediation. But in recent studies,
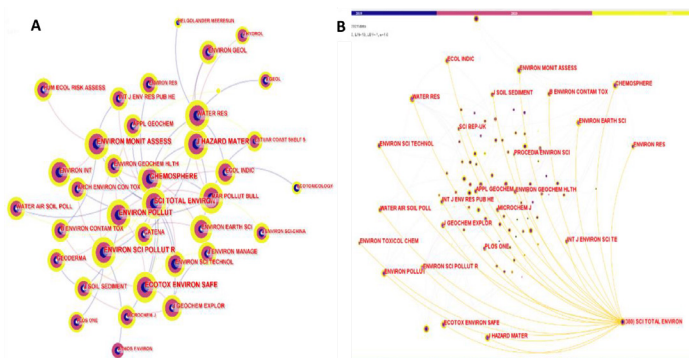
Figure 3: Top 100 journals in the field of Heavy metals (A) and Ranked 1st in prominent journals (Science of Total Environment) (B).

activated carbon shows more efficient results as compared to CNTs.[43]

From the above discussion, it was concluded that due to the increase in industrialization and natural calamities, heavy metal concentrations increase in our environment. It gets accumulated in water as well as soil ecosystem and affects the food web of our ecosystem. To date no such absolute solution is known, still, progress is going on in the field of remediation of Heavy metals. We still do lots of experiments and research which gives reliable results and also apply such policies which help to reduce the use of heavy metal as well helpful to remediate their concentration from the environment at a very effective level.

Prominent Journals

This analysis is employed in this study to examine the structure of subject relationships among journals that publish articles related to heavy metal. It has been considered that co-citation analysis is an efficient method to measure relationships and linkages between journals and to describe mainstream science. In the present study, nearly 500 journals were studied for co-citation analysis, and the top 10 journals are tabulated in Table 3. Out of these, Science of Total Environment ranked first with a co-citation frequency of 380 in terms of the number of articles published in this journal and their citation followed by Chemosphere (343), Environmental Pollution (322), and Environmental Monitoring and Assessment (317). Figure 3(A) presents the co-citation network of the top 100 journals. In this network, journals with high frequency are represented by larger nodes and vice versa. The number of citations represents the influence and importance of that article.[44] However, a few top journals have less frequency but they still published articles on heavy metal with high impact and citations. Figure 3(B) representing the co-citation network of Science of Total Environment concerning other journals shows how much this journal interconnects with other sub-disciplinary journals. Journals with high co-citation frequency may be considered the more visible titles and possibly the more significant.[45]

Table 3: Top 10 Journals represented with Impact Factor (IF), Citation number and h-index.

Journals (2010-2021) with frequency	Impact Factor	Number of Citations	Degree Centrality	Betweenness Centrality	h-index
SCI TOTAL ENVIRON (380)	7.96	7570	21	0.36	45
CHEMOSPHERE (343)	7.08	1065	15	0.15	31
ENVIRON POLLUT (322)	8.07	2157	9	0.06	28
ENVIRON MONIT ASSESS (317)	2.51	636	19	0.17	13
ENVIRON SCI POLLUT R (295)	4.22	1368	9	0.05	16
ECOTOX ENVIRON SAFE (269)	6.68	1056	12	0.11	22
J HAZARD MATER (255)	10.58	586	8	0.03	18
MAR POLLUT BULL (228)	5.55	1216	11	0.08	22
WATER RES (221)	11.24	498	12	0.11	17
ENVIRON EARTH SCI (173)	2.18	11	11	0.08	401

Table 4: Top 10 countries involved actively in the area of heavy metal contamination and remediation.

Country	Frequency	Degree centrality	Betweenness Centrality
Peoples R China	206	15	0.14
India	31	15	0.14
Pakistan	27	11	0.09
USA	23	19	0.19
Bangladesh	23	15	0.15
Iran	20	14	0.12
Nigeria	15	4	0.02
Brazil	14	4	0.01
Saudi Arabia	14	14	0.12
Malaysia	13	9	0.06

In Table 3, the Journal of Science of Total Environment shows a higher centrality value, as well as higher occurrence frequency, which signifies that it has greater influence in the field of heavy metal analysis than others. Since this is an international multi-disciplinary natural science journal might be due to this reason it has a higher number of publications as compared to others.

Figure 4: Countries' network in the area of heavy metal contamination and remediation.
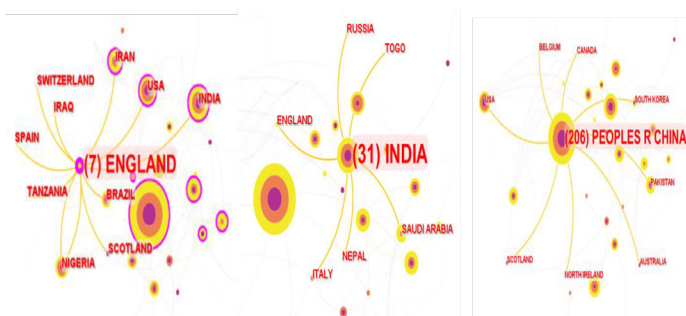

Figure 5: Linkage network of England, India, and China in the area of heavy metal contamination and remediation.

Table 5: Top 10 Institutions involved in research related to heavy metal contamination and remediation.

Institution	Country	Frequency	Degree centrality	Betweenness Centrality
Chinese Acad Sci	China	41	13	0.17
Univ Chinese Acad Sci	China	18	9	0.12
Chinese Res Inst Environm Sci	China	12	5	0.02
Univ Peshawar	Pakistan	10	5	0.03
Noakhali Sci and Technol Univ	Bangladesh	9	5	0.03
Nanjing Univ	China	9	7	0.05
Beijing Normal Univ	China	9	7	0.05
China Univ Geosci	China	8	5	0.03
Patuakhali Sci and Technol Univ	Bangladesh	7	3	0.01
Univ Belgrade	Serbia	6	3	0.01

Figure 6: Institutional networks involved in the heavy metal pollution field.
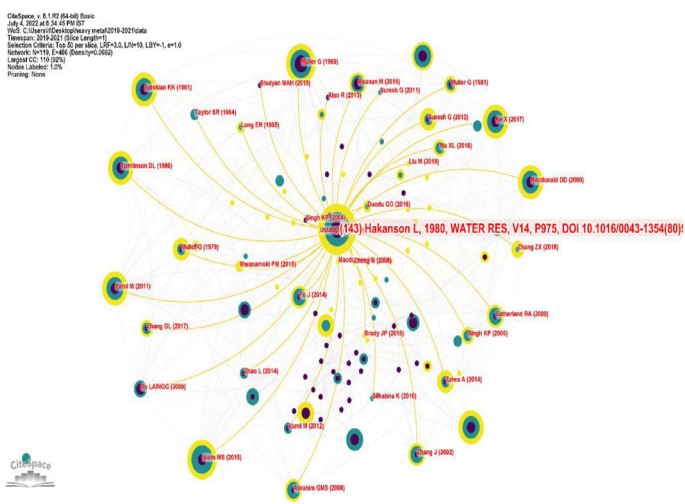

Figure 7: Network of the key author (Hakanson L).

Countries and Institutions Collaboration in Heavy Metal

Major countries involved in research work on heavy metal contamination and remediation are tabulated in Table 4. The worldwide distribution of publications is not uniform. China is the most active country involved in this area of research followed by India, Pakistan, Turkey, and the USA. A low number of publications from Nigeria, Brazil, Saudi Arabia, and subsequent countries might be due to lacking laboratory infrastructure and required scientific skills. Similarly, in the country cooperation network, China shows the highest node size (Figure 4). Although China and India are the two topmost countries in this field, their cooperation is not close and strengthening shows that the author's relationship between these two countries is not so good. In the case of the centrality measure among the top 10 countries, England shows the highest result as compared to China and India (Figure 5). This might be because the number of cooperation links

Table 6: Top 10 Authors involved in heavy metal pollution research in the river system.

| References	Year	Frequency	Degree centrality	Betweenness Centrality
Hakanson L, 1980, WATER RES, V14, P975	1980	143	21	0.28
Muller G, 1969, J GEOL, V2, P108	1969	58	15	0.12
Islam MS, 2015, ECOL INDIC, V48, P282,	2015	54	10	0.09
Tomlinson DL, 1980, HELGOLANDER MEERESUN, V33, P566,	1980	53	18	0.15
Macdonald DD, 2000, ARCH ENVIRON CON TOX, V39, P20,	2000	45	14	0.11
Turekian KK, 1961, GEOL SOC AM BULL, V72, P175,	1961	42	14	0.11
Varol M, 2011, J HAZARD MATER, V195, P355,	2011	35	5	0.03
Yi YJ, 2011, ENVIRON POLLUT, V159, P2575,	2011	32	18	0.14
Ke X, 2017, CHEMOSPHERE, V175, P473,	2017	31	7	0.05
Tessier A, 1979, ANAL CHEM, V51, P844	1979	30	3	0.01
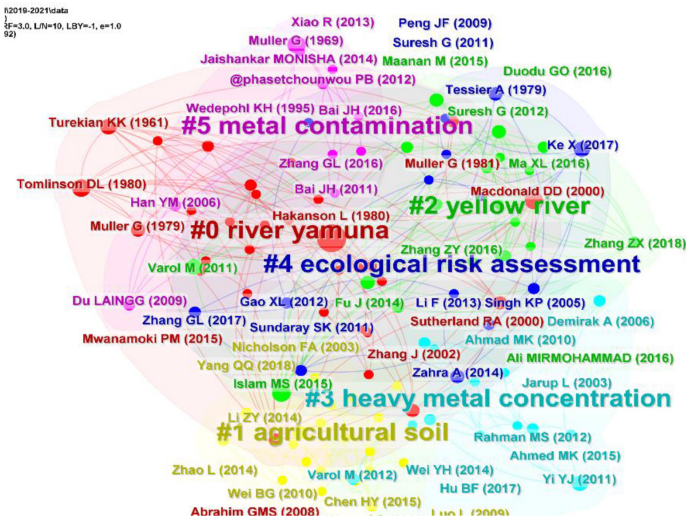
Figure 8: Key Researchers involved in the heavy metal pollution field.

in England is higher than in China and India. This cooperation network shows that heavy metal contamination is still a global problem.

In the case of institutional analysis, again China ranks first in case of occurrence frequency as well as centrality measures (Table 5 and Figure 6). A high degree of centrality indicates that the flow of information is more from Chinese Acad. Sci. This result is also supported by country co-occurrence analysis. This signifies the higher contribution of China in the area of heavy metal contamination and remediation.

Top Researchers in Heavy Metal Pollution

The ten most-cited authors in the specified journals for 2010-2021 are tabulated in Table 6. Authors' sequence in a publication illustrates their contributions and speciality of research, which offers more information as inputs of author co-citation analysis. Figure 7 depicts the network of Hakanson L with other authors

and signifies that he is the most cited author among all. Among the top 10 authors, Hakanson L appears with an occurrence frequency of 143 followed by Muller G and Islam MS with 58 and 54 respectively. The higher value of occurrence frequency signifies that Hakanson L is the most cited author with pioneer work in this area. He discovered the Ecological Risk Index for Aquatic Pollution Control. His focus is not to discover the quality and type of pollution in the aquatic system but he describes how to quantify it. This is the main reason behind his occurrence frequency and large network.

In Figure 8, Scientometrics analysis categorizes the whole data into 6 different groups i.e., Yamuna River, Agricultural soil, yellow river, heavy metal concentration, ecological risk assessment, and metal contamination. Different colours illustrate different authors belonging to that particular area. This analysis signifies that globally, the yellow river from China and the Yamuna River from India are among the most polluted rivers. Numerous research works done on these rivers support this result.[8] Hakanson L at the top position among the top 20 authors belongs to the Yamuna River group while Islam MS is from the Yellow River. This analysis is also supported by country co-occurrence analysis in which China and India are the two top contributing countries in heavy metal pollution research in the river system.

CONCLUSION

Conventional methods in bibliometric analysis, mainly focus on the frequency of keywords, and the number of publication outputs from countries, research institutes, journals, and subject categories. This approach does not completely indicate the development trends within a research field while in recent years, many methods and tools have been used in the bibliometric analysis, such as social network analysis tools and impact factors.[46,47] In this study, we provide a more informed view of the research trends, the most concerned topic, and existing research

gaps in the field of heavy metal pollution. Social network analysis has helped to identify the structure and dynamics of the research networks, the key concepts and nodes that play an important role in the network.[48] Bibliometric analysis methods and indicators such as co-authorship network and co-occurrence of author keywords were used to explore the research trend and hot issues of heavy metal pollution. Overall, the Scientometrics analysis outlines the intellectual structure and its evolutionary trajectory in the last 10 years. The emerging trends and patterns identified by Citespace have provided a novel, intriguing and comprehensive view of how the research on the search topic was conducted and what the potential research key areas would be.

The present study reveals how heavy metal pollution becomes a vast problem in a short period. This illustrates that globally the Yellow River and Yamuna River are the two most polluted rivers. From keyword cluster analysis we reveal that Adsorption has been proven to be a useful method for the treatment of heavy metal contaminated water. For effective control, we should determine the source of heavy metal pollution as well as explore the spatial distribution of heavy metal across the river system. We should develop such policies which help to reduce this pollution and focus on developing an efficient and sustainable method that helps to convert the toxic form of metal ions into a non-toxic form.

The paper connects to the Sustainable Development Goals (SDGs) 6. It especially addresses the two key targets under this 6.1: Safe and Affordable Drinking Water; 6.2: Improve Water Quality, Wastewater Treatment and Safe Reuse.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

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